

بسم الله الرحمن الرحيم

University of Khartoum  
Faculty of Forestry

# **Integration of Remote Sensing and GIS Techniques to improve national forest inventory in Southern Darfur State**

**By**

**Mohamed Osman Mohamed EL Hassan  
Technical University of Dresden  
Germany (1987)**

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**Supervisor:  
Dr. Abdalla Mirghani El Tayeb**

**Faculty of Forestry  
University of Khartoum  
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إهداء

إلى ذلك الشيخ الورع الذي سكبني أحرفا وعلمي  
الحياة.... إلى المرحوم والدي إليه أهدى ريحانة جهدي  
ورحيقه استحياءا مني لروحة الطاهرة  
إلي والدي وزوجتي وبناتي إسراء ، آلاء وملاذ وابني  
الصغير احمد

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.

## **Abstract**

The study aims to compare forest inventory by using ground survey only and combination of ground survey, remote sensing and GIS techniques. This study covered parts of southern Darfur State. It covered about 5986289 hectares that is 45% of the total area of the southern Darfur State.

The main objectives were to show the efficiency of remote sensing and GIS techniques in forest resources surveys and improvement of ground surveys to reduce efforts, time and money expended.

The study used data from the National Forest Inventory (NFI) that was started in March 1995 and completed in July 1997. Data from AFRICOVER project (landsat images) of the same period (1995-1997) provided a good base-line for monitoring environmental changes, extent of forest areas, tree species composition and forest products in the country.

The results show the classification of the land cover and calculations of the total area covered by forests, grazing and agricultural lands. The results also show map of the land cover, land use and crown closure for the trees on the area, the total volume for all trees was calculated. The total forest area from ground survey was 3 588 202 hectare, and the forest area according to land-sat images was 2 746 184 ha. The total woody volume in ground survey was 28 378 353 m<sup>3</sup>, the total volume according to land-sat images was 21 196 384 m<sup>3</sup>.

The combination of ground survey and remote sensing images will be more effective to be used in future national forest inventories, because it reduces the number of sample plots to be laid out, reduces efforts, time

and money expended, in forest inventories.

The results and maps of this study can be used as a basis for updating the National Forest Inventory, and to make extrapolations for estimating parameters of forest areas which were not possible to reach during the NFI.

## خلاصة الأطروحة

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# **Chapter I**

## **Introduction**

### **1.1 Background**

The Sudan is the largest country in Africa, and, like many other countries does not have a reliable measure of its forest resources. Figures appearing in reports such, as the Sudan Energy Handbook (Anonymous, 1987) and the FAO Forest Resource Assessment (Anonymous, 1993) show total forest areas vary from 964,190 km<sup>2</sup> to 432,660 km<sup>2</sup> or between 40.6% and 18.2% of the country's area. The Forests National Corporation legislation also recognizes the importance of forests and states that the forest area of the country should be greater than 20%. Whether the country has 20% forest cover and what the definition of forest is with respect to this requirement has not yet been answered.

A number of regional inventories have been carried out but sheer size of the country has meant that even parts of the Sudan that are known to be forested have not been inventoried. Two types of inventories have been done in the Sudan, namely management inventory and reconnaissance inventory. They differ in purpose, methodology, accuracy of results, costs, and level of detail. A management inventory is carried out for a relatively small area and is the basis for management plans and the subsequent silvicultural or harvesting activities. The accepted level of accuracy is  $\pm 10\%$  at the 95% probability level for all strata combined (Group Poulin, 1984b). These inventories have a high sampling intensity. For example the inventory of Rawashda Forest Reserve (Vink, 1987) used a sampling percent of 0.05%.

A reconnaissance inventory is designed to cover large areas and is used

for planning at a regional or national level. The accepted level of accuracy is  $\pm 20\%$  at the 95% probability level for all strata combined (Group Poulin, 1984b). In comparison with the management inventories sampling intensity is low. The Blue Nile Province inventory had a sampling intensity of .02% (Group Poulin, 1984a) and the 1989/90 Kassala province inventory .0002% intensity (Hellden, 1991). It should be noted that there is a recognized shortfall between the area that is deforested annually and the area afforested or reforested. This is stated in the FAO Project Document (Anonymous, 1992) as 1.5% of the area is deforested annually. In Southern Kassala the demand has been reported as three times the sustainable supply (Masdar, 1992). Since there is such a large gap between the two sides of the demand/supply balance, the expenditure of large amounts of money on further quantifying the problem is difficult to justify.

## **1.2 Importance of remote sensing**

In the scenario of a rapidly expanding world population, changes in land use and declining forest cover, remote sensing has the role of an emerging discipline, and provides essential tools of trade to the field of forestry. In this study, emphasis is placed on the forest applications of remote sensing. The remote sensing system provides unique data that cannot be obtained by any other source; but much more often the collected data facilitates fieldwork and enables tasks to be completed at lower cost and much more quickly. Usually field collected data provide more accurate and precise results, but the collection of the data is slow. In rugged terrain, it may be economically impracticable or confined only to a few ground samples in accessible locations. Ensuing from this is the common forest practice of marrying remotely sensed data and field data

and crosschecking continuously the results of image analysis with field samples.

### **1.2.1 Remote sensing for forest resources**

Airborne remote sensing (ARS) in forestry is effectively aerial photography. Operationally, multispectral scanning has been confined to thermal sensing for fire protection. Side-looking airborne radar (SLAR), until very recently, was used only occasionally to provide small-scale imagery for natural resources reconnaissance surveys and for classifying major vegetal cover types of unmapped areas in developing countries. For research the situation is somewhat different, as evidenced by the use of airborne multispectral electronic scanning (MSS) in simulation studies prior to the launching of Landsat TM (Thematic Mapper) and the Satellite Probatoire pour Observation de la Terre (SPOT).

Many years through the use of aerial photo-interpretation in forest inventory; and this key role of providing forest information through aerial photography at various photographic scales seems unlikely to change in the near future. The aerial photographs are used directly as a substitute for planimetric and topographic maps, and, with some elementary knowledge of photogrammetry, can be used to derive simple thematic maps incorporating information on the forest stock. Image analysis will provide information on forest cover, forest types, forest condition, some tree and forest stand parameters, information on landforms, land use and land potential, and when related to field samples or aerial volume tables, estimates of the timber volume and forest biomass. This can be extended to obtaining information related to water resources, soil degradation, rangeland management, agro-forestry, etc. Unlike the development of airborne remote sensing over many years, the application of satellite remote sensing (SRS) in forestry has developed rapidly in association

with the digital image analysis of earth resources satellite data; and has led at times to overemphasizing what can be achieved.

Care therefore requires to be exercised in distinguishing between sound research and deriving usable information. Sound research has facilitated the development of low-cost computer-assisted analysis systems; but, lack of appreciating the constraints imposed mainly by the pixel size and dependence on spectral differences can lead to overemphasizing the role of satellite remote sensing in forestry, particularly as related to compartments of intensively managed forests.

The leaf (or needle) is a complex structure with its internal tissues and external morphology varying between genera and species. Even for the same species there may be differences in leaf structure as influenced by environmental conditions; and on the same tree differences will exist between leaves fully exposed to sunlight (i.e. sunleaves) and shade-bearing leaves (i.e. shade leaves). However, the shade-bearing leaves are unlikely to contribute to the energy recorded by the remote sensor. Sunleaves (needles) will usually provide all or most of the reflected energy recorded by the sensor unless the trees are leafless or heavily defoliated. The greatest contrast in reflectance within the same tree crown will be provided by the leaf ontogeny. This often results in crown patterns seasonally conspicuous in large-scale images and helps in the identification of some tree species.

It can be demonstrated that even when there are conspicuous differences between the tissues of mature healthy green sunleaves, their spectral reflectance may be similar, and that the presence of spongy parenchyma is not required to provide the spectral reflectance, as sometimes stated in publications (Howard, 1991). As pointed out by Knipling (1970), the



importance of air cavities within the leaf has been overemphasized, and it is doubtful if the spongy mesophyll contributes more than the palisade cells to reflectance. It is probable that all plant cells of the mesophyll reflect irrespective of their shape, size and arrangement. It is likely that variation in spectral reflectance is dominated by differences in the refractive indices between the cytoplasm, cell wall, middle lamella, etc. and as modified by the two-way absorption by leaf pigments (Gausman, 1974).

If hairs or abundant waxes are present on the leaf surface, then the spectral reflectance in the visible spectrum will be increased considerably, for example, observed for white poplar in Minnesota that the top surface had a reflectance of 12%, while the hairy white ventral surface had a reflectance of 50%. If abundant waxes are present as on some young leaves, these will increase considerably the spectral reflectance in the visible and near-IR spectra; but on old mature leaves the waxes may be lost and dust particles contribute more to the spectral reflectance. The lignified tissue of sunleaves, which may be exposed during insect attack, has a low spectral reflectance in the visible spectrum up to about  $0.65\mu\text{m}$  and then rapidly increases in the near IR (Howard, 1991).

### **1.3 Problem statement**

Forests, their products and services play a crucial role in the economy of the Sudan and the life of its people. It has been observed by many that there is an evident change in the forest cover in the Sudan over the last century. Many reports have warned about the declining forest resources and the dire consequences expected. The importance of quantifying and appraising the existent resources and their national sustainable

management was emphasized on many occasions. Figure appearing in various reports show the total forest area varying between 40.6% and 18.2% of the country's surface areas. All these figures are estimates based on observations. A number of forest inventories have been carried out but these are very small area compared to the size of the country even parts of the Sudan that are known to be forested have not been inventoried (NFI.1998). To complete the picture estimates of the available forest resources and related parameters had to be obtained by national inventory .the national forest inventory was start in March 1995 and completed in July 1997. The results of national forest inventory had disadvantage according to

- Its low intensity
- The area of the systematic grid
- Sample size ( 0.2 ha)
- The sample plot represented of 10 km by 10 km
- Horizontal observations

It gives overestimation of the forest area as land cover and land use.

It is possible to improve the national forest inventory estimations with integration of remote sensing and GIS techniques.

#### **1.4 Objectives of the study**

The main goal of this study is to compare and analyze the data of the National Forest Inventory (1995 - 1997) as ground survey inventory, and as land cover class based on remote sensing and GIS map Combined with field , for Southern Darfur State.

Specific objectives are:

1. To show the extent and distribution of natural woody vegetation and density of trees.

2. To reduce the total number of sample plot to be inventoried, to reduce efforts, time and money expended, in forest inventories

## **Chapter II**

### **Literature Review**

#### **2.1 Geographic Information Systems (GIS)**

The term land information system is often used for spatial systems handling landscape data at larger mapping scales. Technology, as a management tool, in the storing, retrieving, analyzing and updating of large quantities of map and forest survey data, has been motivated by budget constraints, the need for quick decision-making and the rapid decrease in computer costs.

A geographic information system (GIS) involves the computer-organized grouping of activities and procedures covering the input, storage and manipulation, retrieval and presentation of spatially based and related data. Each bit of data is spatially referenced and processed digitally within the computer. In the broadest context, a GIS is tailored digitally to the user's data needs and channels the locations of spatial data at the intelligence level of the decision-maker. A geographic information system handles spatial data in terms of their x-, y- and z-co-ordinates and non-spatial attributes of that data. It is much more than a digital mapping system; but, up to the present time, the information output of remote sensing analysis, whether digital or visual, has contributed little as a primary source of the multilayer data stored in a GIS. In most geographic information systems, existing maps have provided the primary inputs (van Roessel, 1986).

Geographic information systems help to reduce human errors and to eliminate many mapping and draughting tasks, and they are quick and efficient in providing spatial information, including multilayered maps, point and line proximity calculations and the interactive transfer of data to and from management information systems and digital imagery analysis systems. Although cost effective in operation, a geographic information system has the serious drawback of being expensive in establishing its data base; and there is usually a lack of readily available spatial data, other than that obtainable from topographic maps, planimetric maps and the occasional thematic map (e.g. soil map, geological map, forest stock map). Large amounts of existing natural resource data are seldom in a form that can be quickly and automatically computer coded and geographically referenced. The usefulness of any GIS will depend primarily on the type, accuracy and detail of the input data it contains (Marble and Pequet, 1983).

## **2.2 The Remote Sensing**

Remote sensing is the science of gathering information about an object through measurements made from a distance, i.e. without actually coming in contact with it. Remote sensing uses electromagnetic energy as a means of detecting and measuring target characteristics. This refers to all energy that moves with the velocity of light in a harmonic wave pattern. The wave concept explains the propagation of electromagnetic energy, which is detectable only in terms of its interaction with matter. On the basis of wave lengths, electromagnetic radiation is classified into regions or bands (Hegyi and Quenet: 1980). Because many remote sensing devices operate in the green, red, and near infrared regions of the electromagnetic spectrum, they can discriminate radiation, absorption and

reflectance of vegetation. One special characteristic of vegetation is that leaves, a common manifestation, are partly transparent allowing some of the radiation to pass through (often reaching the ground, which reflects its own signature). The general behavior of incoming and outgoing radiation that acts on a leaf are shown, (Figure 1.1):

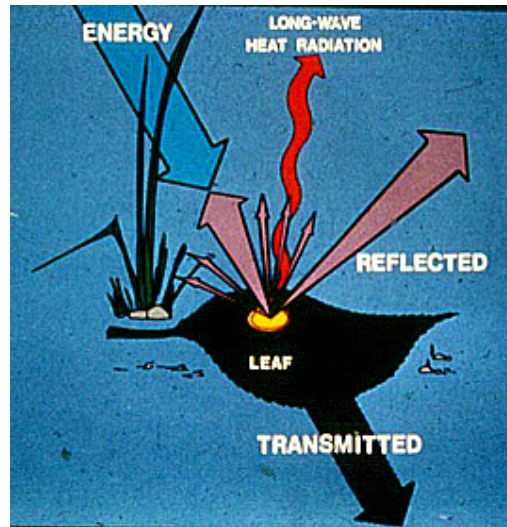


Figure 1.1  
The general  
behavior of  
incoming and  
outgoing radiation  
that acts on a leaf  
(NASA,2002)

### 2.2.1 Leaf pigments

The spectral reflectance curves of the visible spectrum are caused by chlorophyll absorption. The minimal reflectance occurs in the red band of the visible spectrum at about  $0.67\ \mu\text{m}$ , which is important to remote sensing, and in the violet/blue band between about  $0.36\ \mu\text{m}$  and  $0.40\ \mu\text{m}$ , which is out of the range of aerial photographic sensing.

The primary leaf pigments of higher plants are chlorophyll-a with maximum absorption at about  $0.43\ \mu\text{m}$  and  $0.66\ \mu\text{m}$ , chlorophyll-b, with absorption peaks at about  $0.45\ \mu\text{m}$  and  $0.65\ \mu\text{m}$ , and the carotenoid pigments (carotene B, xanthophyll). Phytocyanins have a high absorption in the UV, attain a maximum at about  $0.50\ \mu\text{m}$  and absorb strongly again in the mid-IR. Phytocyanins, when present as red pigment, will contribute considerably to the absorptive and reflective properties of the leaves.

With many deciduous forest trees, as leaf senescence approaches in autumn, there is a rapid change in pigments from chlorophyll to anthocyanins.

A logical explanation of the characteristic shape of the spectral reflectance curves (Figure 1.2) of recently mature sunleaves is provided by examining the spectral transmittance curves of suspended leaf pigments in solution. If it is assumed that the solar radiation reflected internally by the leaf tissue passes twice through the leaf pigments, the derived curve will approximate to the spectral reflectance curve of an intact leaf (Howard, 1991). Experimentally, it is also readily shown using a spectroradiometer that the spectral reflectance of green leaf pigments suspended in solution is negligible (Howard, 1991); and that the transmitted energy by the leaf pigments provides the characteristic curve shape to be observed for the reflectance of intact leaves (Figure 1.2).

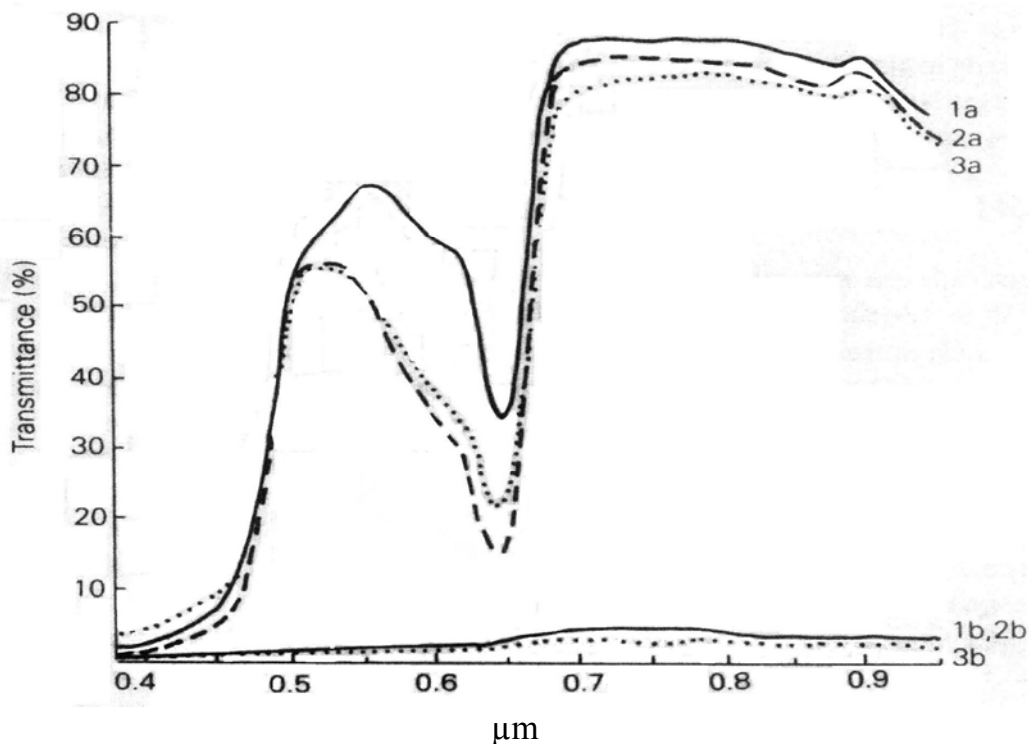
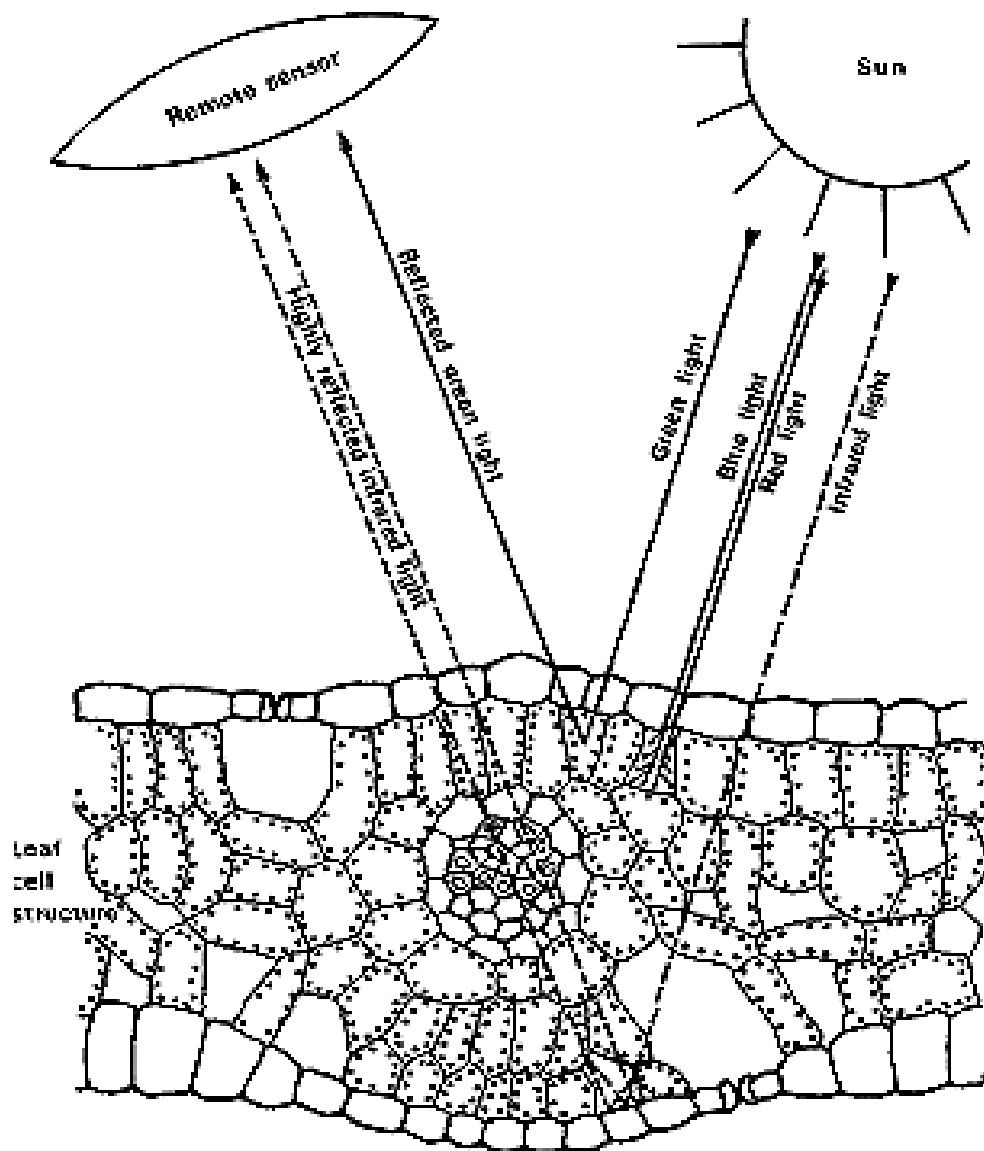


Figure 1.2 the spectral reflectance curves (Howard, 1991)

The abrupt change in reflectance and transmittance between about 0.65  $\mu\text{m}$  and 0.75  $\mu\text{m}$  coincides with the change in energy absorption for electron excitation to molecular vibration which requires considerably less energy. A shift to the left or right in this part of the spectral curve is commonly termed red shift, and is receiving increasing attention in research related to remote sensing of plant condition. Figure 1.3 considering which traces the influence of green leafy material on incoming and reflected radiation



Absorption centered at about  $0.65 \mu\text{m}$  (visible red) by chlorophyll pigment in green-leaf chloroplasts that reside in the outer or Palisade leaf, and to a similar extent in the blue, removes these colors from white light, leaving the predominant but diminished reflectance for visible wavelengths concentrated in the green. Thus, most vegetation has a green-leafy color. There is also strong reflectance between  $0.7$  and  $1.0$



$\mu\text{m}$  (near IR) in the spongy mesophyll cells located in the interior or back of a leaf, within which light reflects mainly at cell wall/air space interfaces, much of which emerges as strong reflection rays. The intensity of this reflectance is commonly greater (higher percentage) than from most inorganic materials, so vegetation appears bright in the near-IR wavelengths. These properties of vegetation account for their tonal signatures on multispectral images: darker tones in the blue and, especially red, bands, somewhat lighter in the green band, and notably light in the near-IR bands (maximum in Landsat's Multispectral Scanner Bands 6 and 7 and Thematic Mapper Band 4 and SPOT's Band 3).

Identifying vegetation in remote-sensing images depends on several plant characteristics. For instance, in general, deciduous leaves tend to be more reflective than evergreen needles. Thus, in infrared color composites, the red colors associated with those bands in the 0.7 - 1.1  $\mu\text{m}$  interval are normally richer in hue and brighter from tree leaves than from pine needles. These spectral variations facilitate fairly precise detecting, identifying and monitoring of vegetation on land surfaces and, in some instances, within the oceans and other water bodies. Thus, we can continually assess changes in forests, grasslands and range, shrub lands, crops and orchards, and marine plankton, often at quantitative levels (F.F. Sabins, 1987). Because vegetation is the dominant component in most ecosystems, we can use remote sensing from air and space to routinely gather valuable information for characterizing and managing of these organic systems.

Remote sensing has its origins in spy satellites, such as the US Corona and Soviet Zenit satellites, which took high resolution pictures of targets and dropped the film to earth for processing. Technological advances,

such as the development of digital electronic sensors, allow satellites to gather images, and download that information directly to receiving stations on earth. This dramatically reduces the time between imaging and analysis, allowing faster response times with any remotely sensed information. Remote sensing satellites can be divided into two broad categories, based on the resolution and scale of their imagery. Environmental observation satellites, such as Japan's Marine Observation Satellite (now defunct), have low resolution and produce broad-scale images. They usually monitor ocean temperature, changes in vegetation, or other large-scale environmental phenomena. With the exception of meteorological satellites, most environmental observation satellites have limited dual-use applications (F.F. Sabins, 1987).

Other remote sensing satellites collect highly detailed, small-scale imagery, and have clear dual-purpose utility. Military and intelligence satellites are the ultimate example of this second category of remote sensing satellites. Today, satellite reconnaissance is an increasingly important intelligence gathering mechanism, with sensor resolutions on some military and intelligence satellites estimated to be better than 10 cm. While most imagery is in the visible spectrum, other parts of the spectrum are useful as well. For example, synthetic aperture radar sensors can penetrate cloud cover and the dark of night. Currently, visible light sensors with a resolution between 0.5 meters and 2 meters are considered high resolution. (S.A. Drury, 1990.)

### **2.3 The Landsat image**

The Landsat Program has provided over 34 years of calibrated high spatial resolution data of the Earth's surface to a broad and varied user community, including agribusiness, global change researchers, academia, state and local governments, commercial users, military, and the

international community. Landsat images provide information meeting the broad and diverse needs of business, science, education, government, and national security. The mission of the Landsat Program is to provide repetitive acquisition of high resolution multispectral data of the Earth's surface on a global basis. Landsat represents and others source of global, calibrated, high spatial resolution measurements of the Earth's surface that can be compared to previous data records (NASA, 2000). The data from the Landsat spacecraft constitute the longest record of the Earth's continental surfaces as seen from space. It is a record unmatched in quality, detail, coverage, and value. The Landsat platforms carry multiple remote sensor systems and data relay systems along with attitude-control and orbit-adjust subsystems, power supply, receivers for ground station commands and transmitters to send the data to ground receiving stations. The most recent Landsat mission, Landsat 7, offers these features (NASA, 2000)

- **Data Continuity:** Landsat 7 is the latest in a continuous series of land remote sensing satellites spanning 32 years.
- **Global Survey Mission:** Landsat 7 data will be acquired systematically to build and periodically refresh a global archive of sun-lit, substantially cloud-free images of the Earth's landmass.
- **Affordable Data Products:** Landsat 7 data products will be available through the Earth Resources Observation System (EROS) Data Center at the cost of fulfilling user requests (COFUR).
- **Enhanced Calibration:** Data from the Enhanced Thematic Mapper plus (TM+) will be calibrated to better than 5% absolute, providing an on-orbit standard for other missions.
- **Responsive Delivery:** Automated request processing systems will provide products electronically within 48 hours of order.

The continuation of the Landsat Program is an integral component of the U.S. Global Change Research Program. Landsat 7 is part of a global research program known as National Aeronautics and Space Administration NASA's Earth Sciences Enterprise, a long-term program that is studying changes in Earth's global environment. The goal of Earth Sciences Enterprise is to provide a better understanding of natural and man-made environmental changes. In the Landsat Program tradition, Landsat 7 will continue to provide critical information to those who characterize, monitor, manage, explore, and observe the land surfaces of the Earth over time (NASA, 2000).

### **2.3.1 Previous Missions**

Landsat satellites have been providing multispectral images of the Earth continuously since the early 1970's. A unique 34 year data record of the Earth's land surface now exists. This unique retrospective portrait of the Earth's surface has been used across disciplines to achieve improved understanding of the Earth's land surfaces and the impact of humans on the environment. Landsat data have been utilized in a variety of government, public, private, and national security applications. Examples include land and water management, global change research, oil and mineral exploration, agricultural yield forecasting, pollution monitoring, land surface change detection, and cartographic mapping. Landsat 7 is the latest satellite in this series.

The first was launched in 1972 with two Earth viewing imagers a return beam vidicon and an 80 meter multispectral scanner (MSS). Landsat 2 and 3, launched in 1975 and 1978 respectively, were configured similarly. In 1984, Landsat 4 was launched the MSS and a new instrument called the Thematic Mapper (TM). Instrument upgrades

included improved ground resolution (30 meters) and 3 new channels or bands. In addition to using an updated instrument, Landsat 4 made use of the multimission modular spacecraft (MMS) which replaced the Nimbus based spacecraft design employed for Landsats 1-3. Landsat 5, a duplicate of 4, was launched in 1984 and even in (2000) after 16 years - 11years beyond its 5 year design life - is still returning useful data. Landsat 6, equipped with a 15 meter panchromatic band, was lost immediately after launch in 1993. (NASA, 2000).

## **2.4 Previous Forest Inventories in the Sudan:**

The following review of Sudan forest inventories is therefore confined to the reconnaissance type as the cost of management inventories are usually about \$1/ha , while reconnaissance inventories are significantly less than that figure, usually less than \$.05/ha. Also management inventory methodology is not usually suitable at a national level. (The exception to this statement is when the area to be reported on has already been covered by higher intensity management inventories and a national inventory can be created from them (Bonner, 1987).

### **2.4.1 Blue Nile Province Inventory**

The earliest inventory that has been examined was the Blue Nile Province Inventory carried out in 1983/1984 by Goupe Poulin. This inventory followed the standard North American methodology of aerial photography to determine area and fieldwork in the form of randomly located plots to determine wood volume (Glen, W.M. 1996).

The work appears to have been well done, although it was expensive (approximately \$4/ha, current costs in Canada for this type of inventory are approximately \$1/ha) and there was little involvement of the Sudanese

forestry personnel. This later item meant that there was no continuation of this work after the Canadian team left. It is of note that the field plots used were fixed area plots of 20 by 100 meters (Group Poulin 1994).

This type of inventory is very suitable as a management inventory in areas of importance to the FNC. As costs are high it should probably be confined to areas where the value of the forest can justify the expense, for instance *Acacia nilotica* plantations along the Blue Nile River.

#### **2.4.2 Wad Kabo Inventory**

The Wad Kabo and Rawashda Forest Reserve Inventory which was carried out in 1987 provided a good example of a systematic sampling methodology that can be used to produce both area and volume statistics (Vink,1989). This methodology was chosen because aerial photography was not available. The systematic design was based on sample plots along parallel, equidistant lines. A distance of 500 m between inventory lines was chosen as a compromise between mapping precision and time spent on the fieldwork. Lines were situated parallel to the Western fireline of the forest, to orient them along its long axis. Line 1 was started 250 m east of the western fireline.

The railroad, which forms Rawashda forest's northern boundary constituted a convenient baseline, after adjusting of the later-line distance as measured along the railroad to compensate its azimuth in relation to that of the western fireline. Inventory lines were surveyed right through, from north to south .For practical purposes the forest was divided into 3 sections, which have been inventoried in sequence, as separate units.

- Section 1    railroad to Gedaref-Kassala motor road.
- Section 2    motor roads to the main khor, which crosses Rawashda

forest from west to east.

- Section 3 main khor to southern fireline.

The inventory grid consists of 30 lines; numbered consecutively 1 - 30, from west to east with a total length of 527 km. Rectangular plots of 20 x 100 meters were set out on either side of the surveyed inventory line. Rectangular plots are easier to establish than circular ones (unless the latter are very small). Orienting the plot along the surveyed access line is cost effective. A plot width of 20 m permits rapid checking of dubious borderline trees even in fairly dense *Acacia seyal* stands.

A plot size of 0.2 ha was selected, as a compromise between the increased sampling precision for a given sampling percent from small plots and the need to have a fairly representative image of the forest within each sample unit. This cannot be obtained from small plots, which, moreover, have in total more borderline trees as potential sources of error. Spacing between sample plots centers along the inventory line was arbitrarily set at 500 m, giving a sampling present of 0.8%, again as a compromise between accuracy and expenditure.

Sampling precision is difficult to estimate in a systematic design, although the latter is generally regarded as at least equal to a random design of the same sampling intensity, in terms of sampling error, using the (random design) formulas. The challenge that was faced at that time is to know where the plots were and to this end extensive efforts were expended in cutting survey lines between plots. Had Global Positioning Systems (GPS) devices been available, this inventory would have been much more effective. Other problems noted by Vink (1989) were the time required for data entry and compilation (many years were needed for this job). It should be noted as well, that while Vink (1989) called this a

reconnaissance inventory, the sampling intensity was such that it was closer to a management inventory. Another management inventory was recently conducted in El Ain using a very similar methodology (Vogt, 1994).

### **2.4.3 Eastern Region Inventory**

Efforts to overcome the problems of availability and high costs of aerial photography then focused on the use of satellite imagery (Reichert, 1986). In 1987 a pilot study was conducted by a team from Lund University in the Gedaref area and based on the results; the project was expanded to cover the whole of the Kassala Province in 1988.

It expanded again in 1990 to cover the whole Eastern Region (Hellden, 1991). This project used Landsat Thematic Mapper (TM) data combined with field work to map the woody biomass of 580,000 km<sup>2</sup>. The costs of the inventory were \$.015/ha, but unfortunately the resulting maps and data have proven to be inaccurate. The low volumes of woody material per hectare and the seasonal changes of spectral signature given off by the vegetation appear to have been the problem with this project (Stibig, 1990). The number of field plots associated with this project was only 88, although notations of cover types were made every kilometer during field visits. (Comments by FNC staff indicated problems with the locational accuracy of the plots used to classify the satellite images.) The TM imagery has a resolution of 30 meters and the small crown sizes and low numbers of trees per unit area appear to have caused problems that might have been overcome with higher resolution (and higher cost) imagery, such as that provided from the French SPOT satellite.

The estimates by the Lund team based on the quarter million sheet map



containing the forests are 20-30%. It appears that in this case the woody biomass has been over estimated, while in other areas particularly the Khartoum Green Belt under estimation has occurred. The crown closure estimates were used to determine woody biomass distribution but no details regarding species, size, or number of trees were produced making the output from this project of limited use to the FNC.

It is concluded that the use of satellite imagery of this resolution is not suitable for mapping tree cover in areas where the number and size of trees are low such as the semi-desert and low rainfall savanna regions of the Sudan without more ground checking and accurate locational information of the field plots. Also the lack of basic inventory statistics such as stems per hectare by species was a major short coming for this approach to be used for a National Inventory (William M.Glen, 1995).

#### **2.4.4 Sudan Reforestation and Anti-Desertification/ Sudan Resources Assessment and Development Projects (SRAAD)**

At the same time as the Kassala project was being undertaken a separate initiative was being conducted in western Sudan under the name of the Sudan Reforestation and Anti-Desertification (SRAAD) Pilot Project. This project also utilized TM data but used a much higher number of field plots. This project also used GPS to determine the location of the plots within the range of 20 meters error. The use of these devices avoided the problems faced in Wad Kabo by Vink (1989) and some of the problems faced by Hellden (1991). The plots were laid out systematically on a seven kilometers by seven kilometers, grid and all trees greater than five centimeters at root collar were measured. The resulting information was used to produce the necessary stand and stock tables and total volume statistics.

The TM imagery of the area was classified based on field observations. The project used both image analysis and Geographic Information System (GIS) technology. Equipment was installed in Khartoum and FNC staff was trained in its use. The American support for the project was withdrawn in 1990 but the work continued as the Sudan Resources Assessment and Development Project (SRAAD). The subsequent work used a 10 km by 10 km grid but otherwise was unchanged (Obeid and Hassan, 1992).

The SRAAD project was the first to use GPS and GIS technology in forest inventory in the Sudan and has produced satisfactory results. The volume information produced by the project, however, utilized volume equations which gave negative volumes for small trees. This limitation was a reflection of the equations used, not the methodology employed to collect the data. (It should be noted that Vink also had problems with, volume equations which produced negative volumes for small trees.) No plots were re-measured to determine the accuracy/precision of the field measurements. These limitations should be corrected in future forest inventories.

#### **2.4.5 National Forest Inventory of the Sudan**

The National Forest Inventory (NFI, 1996) collects and communicates information on County's forests. It aims to provide a single authoritative source of data at the national level. The new and updated forest information produced by the NFI (1996) is used at regional, State and national levels by governments. It plays a particularly important role in the development of a national policy and investment framework. Estimating forest attributes has been the task of both forest companies

and provincial governments. Large GIS databases of forest polygons exist to provide inventories of basic tree parameters by way of species composition, quantity, density, height, site index, and crown closure. These parameters are then used to estimate forest species areas, timber volumes, biomass, etc.

#### **2.4.5.1 National Forest Inventory (design and the work).**

It has been designed with the skills, experience and resources of the Forests National Corporation (FNC, 1994) in mind and the time frame of completion before the end of 1996. It can also incorporate detail from management level inventories as they become available. The use of the Global Positioning System (GPS) allows the inventory to become a continuous forest inventory (CFI).

The basis of this methodology is the measurement of fixed area plots on systematic grid throughout the area to be inventoried. The plot locations are determined by GPS and the plot detail is similar to that used in the SRAAD projects.

The sampling grid to be used may be varied depending upon the value of the forest in the area to be sampled. It is suggested that the sample grid for an area remain constant for a quarter million map sheet. Initial recommendations are that all areas south of 16 degrees north, latitude and as far south as is possible be sampled using a 10 km grid. (This is the grid used by the SRAAD project (SRAAD1990) for all map sheets after the initial pilot). Areas farther south should be sampled (When the area becomes accessible) by the 10 km or. a 5 km grid depending on the forest conditions (Note, in the southern areas of the country with dense tree cover the plot design will probably have to change from fixed area to

variable radius plots. If this is the case then care will have to be taken in the training of the field crews so that these plots are correctly measured). It is estimated that 8,000 plots will be required to cover the area which was surveyed by the wood consumption study (Anonymous, 1994).

Because the sampling is systematic, the measured plot is assumed to be representative of the sampling cell (i.e. 10 km by 10 km). The chance of the plot falling into any particular land use or forest type is proportional to the occurrence of that type in a given area (SRAAD, 1990). The land use or forest type of the plot can be shown on a geographic representation of the area. The resulting map will have block (pixel) sizes equal to the sampling grid. Determination and rough land use/forest type distribution can be obtained from the plot data alone.

#### **2.4.5.2.1 Fieldwork**

The fieldwork will generally follow the procedures used in the SRAAD project. The plot size is 20 by 100 meters with a regeneration subplot of 1 by 10 meters and the plot orientation is east west. The plot shape is such that it requires careful attention to layout and area determination. Diagonal measurement or other similar procedure should be used to insure its integrity. Plot descriptors will follow the SRAAD model and measurements to be made are diameter at root collar for most species, tree height and crown diameter. The specific tree measurements required will be determined by mensurational work to be conducted prior to the national inventory.

Plot locations was determined by the FNC Inventory Section's Geographic Information System (GIS) and down loaded to the field supervisor's portable computer. The locational information is

subsequently down loaded into the field crews' GPS and Portable Data Recorders (PDR). It was proposed that the measurements will be recorded using PDRs. The use of these devices has a number of important advantages;

- Data entry is done at the time of measurement and is available for immediate processing and rapid reporting of results.
- The PDR prompts the tally man for all the required information so that it is less likely for data not to be recorded.
- check routines programmed into the PDRs can prevent a number of errors that are difficult to rectify at a later time (i.e. only set species codes can be entered, diameter and height can be examined to see if there is an obvious error.

At the end of each day of fieldwork the PDRs are up loaded to the field supervisor's portable computer and a check program is run to examine the data from each plot. The data should be examined by the field supervisor and for any plots that do not appear correct, the field crew can be questioned while the plot is still fresh in their mind or the plot can be revisited the following day if necessary.

The same check routines will be available for error catching but this may mean revisiting plots more often when errors are detected.

The detailed plot data is sent by the field supervisor to headquarters for final compilation. Backup copies of all data files must be kept by the field supervisor and a printed copy of the data should also be made in case of computer failure.

#### **2.4.6 AFRICOVER (Landsat TM image) inventory**

The AFRICOVER project was initiated by the Food and Agriculture Organization of the United Nations (FAO) on the request of several African countries to provide accurate and reliable Land cover information, based on systematic and harmonized land cover classification system.

The definition of land cover is fundamental, because in many existing classification and legends it is often confused with land use it is defined as: Land cover is the observed bio-physical cover on the earth' surface.

Compilation of the AFRICOVER land cover map has been based on the multi-phase image interpretation approach, which was successfully used by FAO in a number of projects (e.g. land cover mapping of Afghanistan). The real interpretation chain is preceded by a series of preparatory activities: selection of satellite dataset. Selection of best type of data, best time of acquisition, best image quality etc. and selection and, ordering of country ancillary data.

#### **2.4.6.1 The interpretation chain (main phase)**

For interpretation it's necessary to create a virtual preliminary legend use Land Cover Classification System (LCCS). On the base of ancillary data information, a list of the whole potential land cover classes will be created. For preliminary interpretation delineation of land cover polygons as they can be seen from the satellite data will be done. During this phase the "virtual" legend will be continuously updated /modified to adhere to reality as seen from remote sensing data. The end of this phase will produce a preliminary interpretation and a preliminary country legend. On the bases of the interpretative uncertainty highlighted during the preliminary interpretation a portion of map units will be selected for field checking. This first set of points will be integrated, if necessary, by an

extra set of checks to assure a good statistical representation of the land cover classes.

#### **2.4.6.2 Fieldwork Execution for Land-cover.**

Fieldwork is executed by the local photo-interpreters using a fully standardized methodology. “Intermediate” interpretation accuracy will be done using field data. This information will allow the photo-interpreters to evaluate, in a rather objective way, the work done in the preliminary phase of interpretation. Using field information and knowing the “intermediate” accuracy reached in the first phase of interpretation the preliminary legend will be modified/updated (classes with lower accuracy could be aggregated or new classes can be created). Using this more balanced set of land cover classes the previous interpretation will be corrected/modified to reach at the end the final interpretation result and the final legend.

The next step is finalization of land cover layer through editing, digitization, coding and geographic referencing of land cover polygons to facilitate their follow-up the last step is the GIS processing and integration of land cover and basic topographic layers in a comprehensive digital land cover database (Di Gregorio, A. 2002).

## **Chapter III**

### **Study Area**

#### **3.1 Location**

The study area covers the area of Southern Darfur State between latitudes 10° to 12° N, extending from the western to the eastern boundary of the State between longitudes 24° -27° E covering 4 quarter million sheets: these are Idd elfrsan, Abu Gabra, Buram and Abu Mattariq. The study area is situated in the low rainfall savannah ecological zone according to Harrison and Jackson's classification (Harrison and Jackson, 1958). The mean annual rainfall varies between 400 mm and 800 mm. The rainy season starts in May or June and continues for four months. The mean annual temperature vary between 28° C and 35°C in the whole area. The coldest month of the year is January and the hottest months are April, May and June (El-Tom M.A. 1975).

#### **3.2 Climate**

The dominant climatic feature in Southern Darfur is the rainfall pattern associated with the northward movement of the Inter-Tropical Convergence Zone (ITCZ) in May to June. Moist tropical air from equatorial regions is brought into contact with the hot north winds from the Saharan desert. The converging air masses lead to the formation of convective storms, which prevail over the area until the ITCZ retreats southwards in September to October. Rainfall in the study area is highly variable and follows a general north-south gradient from 400-500mm in the north falling between July and September, to 800mm in the extreme south with a rain season extending from May to October. As rainfall decreases, its amount and distribution become more erratic and unreliable



(EL-Tom M.A.1975).

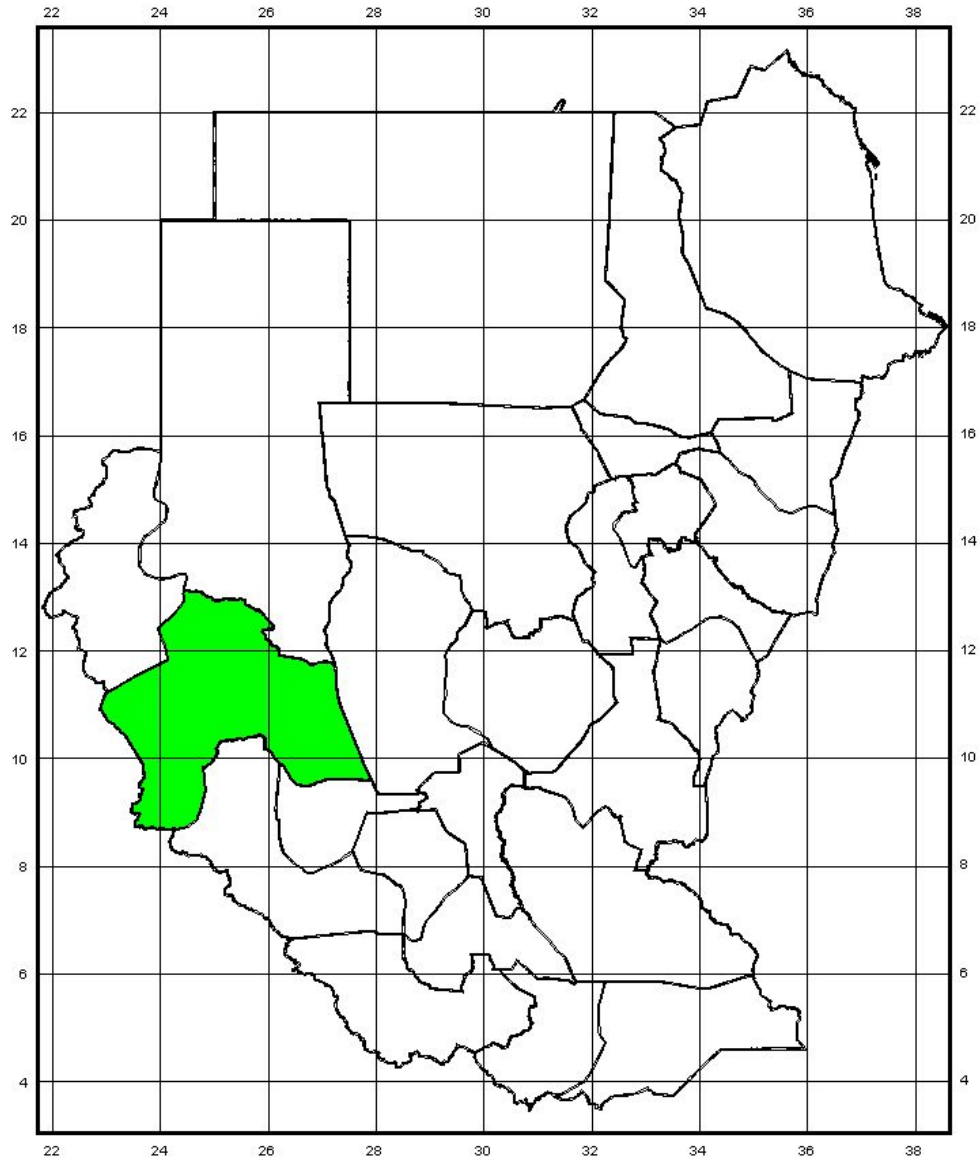


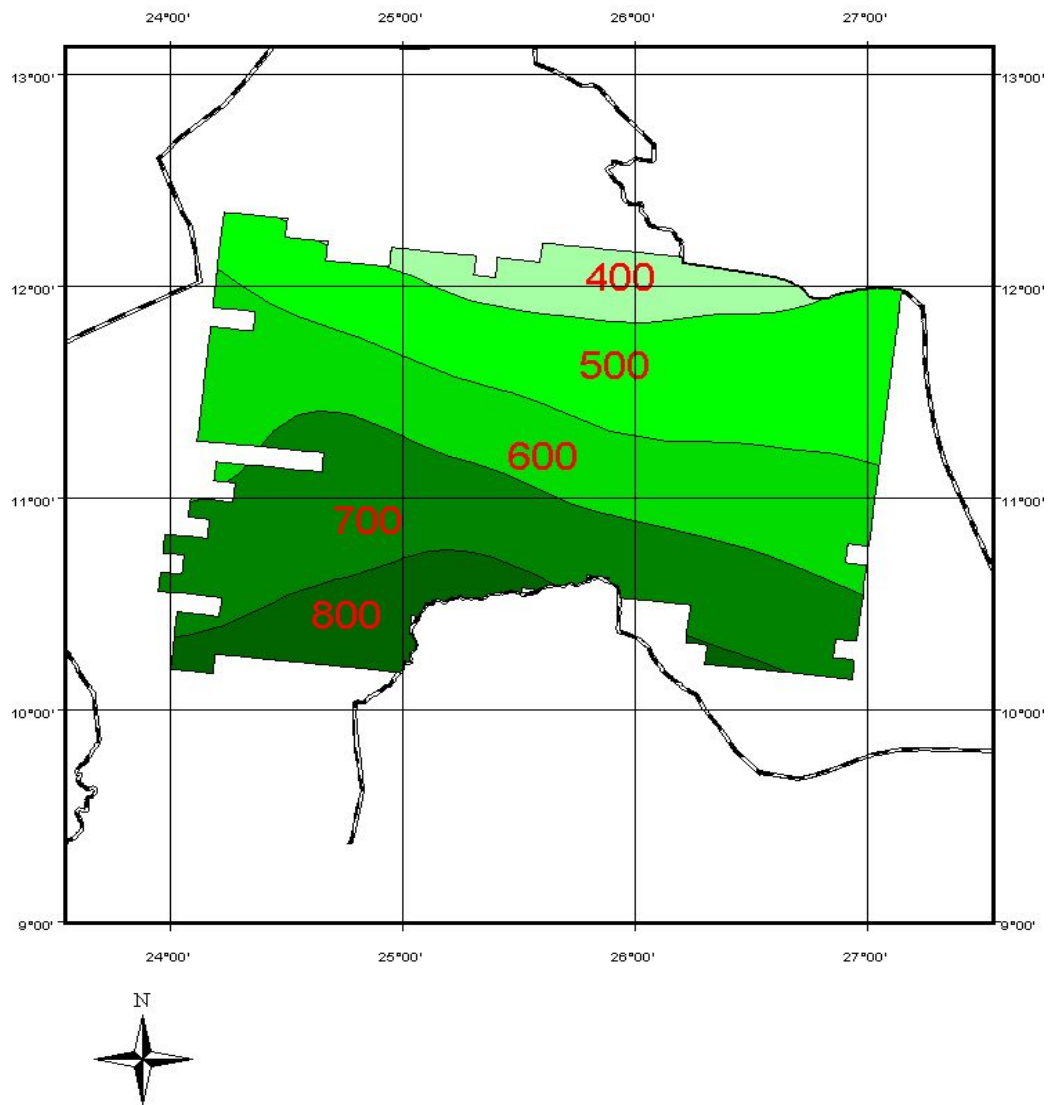
Figure 3.1

Study area Southern Darfur State



Evaporation follows a gradient opposite to rainfall with about 2500mm/annum in the north to 1500mm in the south. Temperatures are moderate to high throughout the year with greater daily and seasonal variation at more northern latitudes. Figure 3.2

Figure 3.2 annual rainfalls in the study area



### 3.3 Geomorphology and Soils

The major landforms and soils found in the study area can be briefly described as follows:

1. Nubian sandstone on the desert fringe overlies the Basement Complex in most locations, forming a flat to gentle undulating surface

with isolated flat-topped hills of low relief. Soils are primarily of mixed composition and in advanced stages of erosion leaving loose sands and hard surfaces of non-cracking clays and sandy clays, or layers of gravel and stone.

2. Stabilized sandy or Qoz soils form extensive, gently-rolling sheets and dunes from the Basement Complex zone to the Baggara and Regeba repeating soil-patterns, The Qoz sands originate from a portion of the deep Aeolian mantle, with quartz sands derived from the surrounding Basement Complex, Nubian Sandstone .These soils are generally very low in fertility and organic matter, and highly susceptible to erosion. They are widely cultivated, which has accelerated water and wind erosion (Pacheco R. and H.A.Dawoud, 1976).

3. The Basement Complex formation in the study area is characterized by steep, rocky hills or mountains with slightly inclined foot-slopes of coarse sandy loams and clays, merging into recurrent patterns on the plains of cracking and non-cracking clays. The hillside and foot-slope soils are inherently low in fertility, though commonly cultivated, and are undergoing moderate to rapid erosion. Cracking and non-cracking clays are products of in-situ weathering or erosion from the hill masses; the former soils being relatively fertile and widely cultivated, and the latter having a hard, impermeable surface resulting in high run-off.

4. Non-cracking clay pediplain soils are derived Basement Complex rock, and consist of flat to mildly wave like plains of alternating deposits of red clays, brown sandy loams and sandy clays. Their characteristics similar to those described in (3) above.

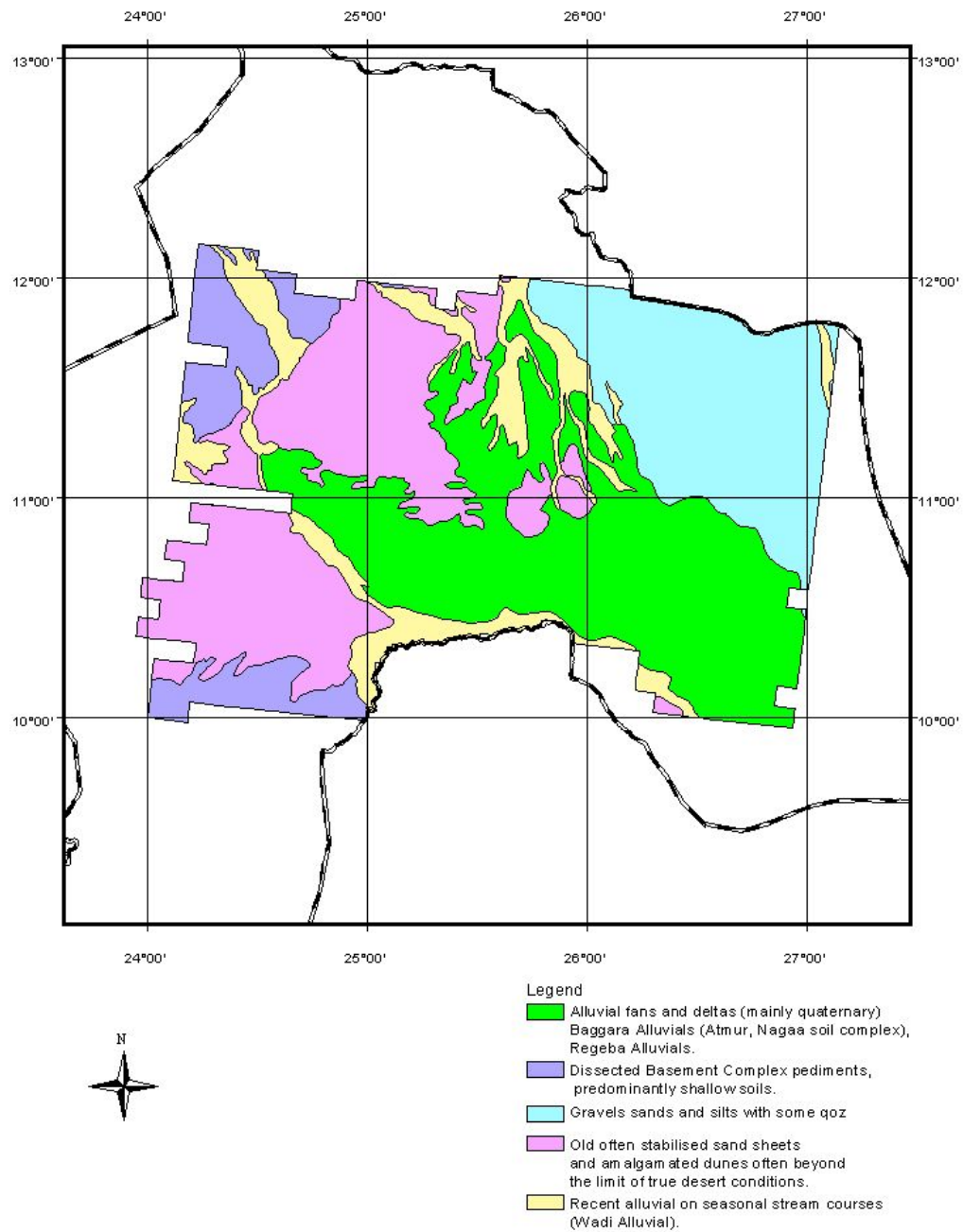
5. Dark cracking clays occur in seasonally flooded lands and adjacent to the river networks of Bahr el Arab. These soils appear too fertile but prolonged water-logging precludes cultivation.

6. Baggara Catenary Soils occurring in the study area form a

topographical sequence of undulating sandunes and various loamy soils, sloping onto non-cracking clay flats and terminating in depressions of dark cracking clays as Butas which are seasonally waterlogged. Buta soil; fairly high in fertility, but because of their discretion as well as tillage problems due to flooding, are not utilized for cultivation.

7. Regeba Catenary Soils are found adjacent to the Baggara soils and exist as a repeating pattern of non cracking clays, alternating with black cracking clays and buta flooded clays. Figure 3.3 show the soil classes in the study area (Pacheco R. and H.A.Dawoud, 1976).

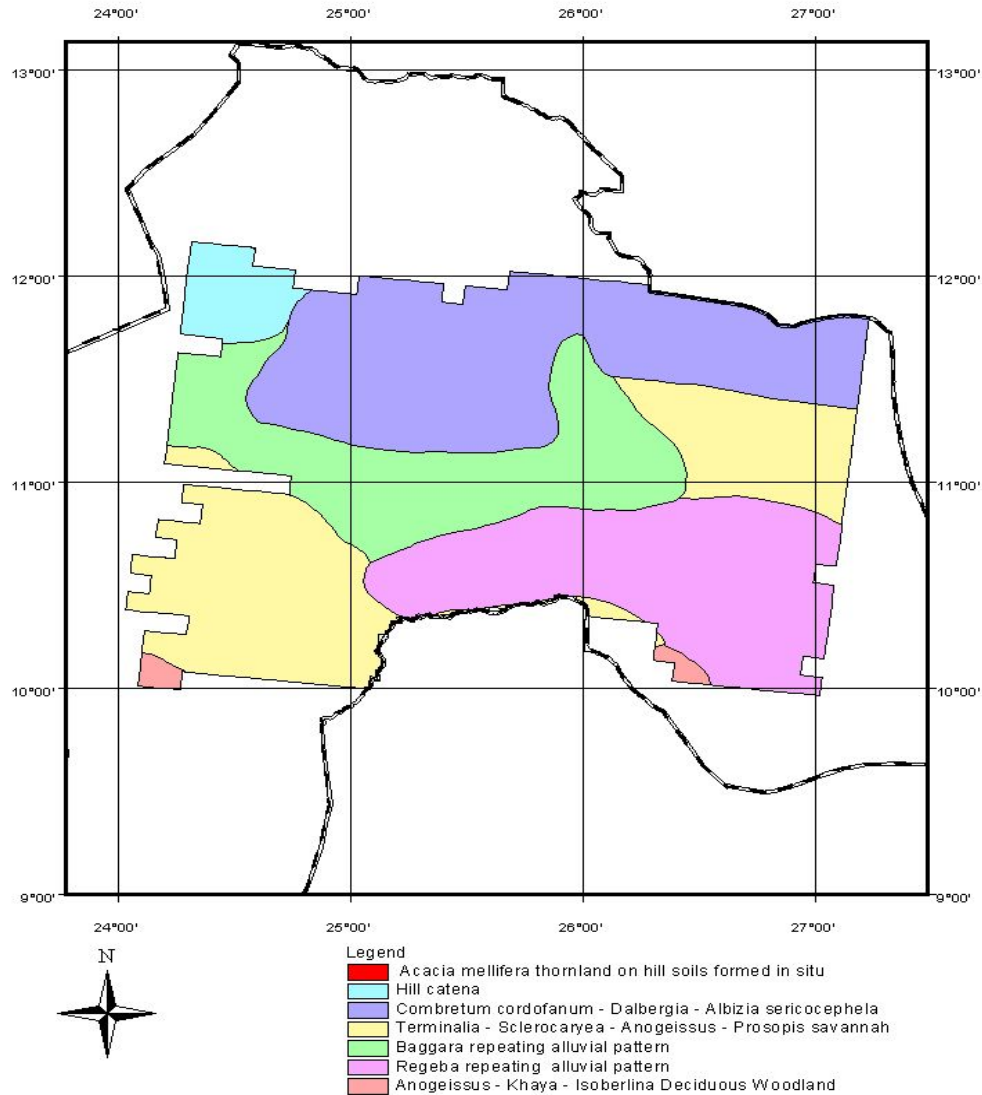
Figure 3.3 soil map of the study area



### 3.4 Vegetation

Vegetation of the study area can be classified into broad ecological zones based on climate and soils. General physiological and botanical characteristics are presented here. (Figure 3.4)

Figure 3.4 vegetation map of the study area (according to Harrison & Jackson 1958)



In the 400-600 mm/annum rainfall belt, a deciduous bush-land savanna exists which is dominated on qoz soils by *Albizia amara*, *Dalbergia*

*melanoxylon.*, *Combretum cordofanum*, and *Acacia Senegal*, while non-cracking clays are populated by *Acacia mellifera* and *Acacia nubica*. Grasses also occur. They form a more continuous cover and include species such as *Andropogon gayanus*, mainly on clay soils, and *Eragrostis tremula* and *Ctenium elegans* on sands. As rainfall approaches 600mm/yr. *Guiera senegalensis* becomes a dominant shrub with occasional, emergent trees like *Sclerocarya birrea*, *Terminalia brownii* and *Cadaba species*.

Within the rainfall zone of 600-800 mm/annum wooded savannas and woodland are found. The structure and composition of vegetation shows considerable variability due to the complex heterogeneity of soil types. Basically, five broad categories of vegetation can be distinguished:

(1) Deciduous broad-leaved woodland and wooded grassland on jebel hillsides dominated by *Boswellia papyrifera* and *Combretum Hartmannianum*, with *Hyparrhenia confinis*, *Pennisetum pedicellatum* and *Panicum species*. in the herb component,

(2) mixed deciduous and thorn wooded grassland on coarse textured footslopes with dominant trees including *Albizia amara*, *Balanites aegyptiaca*, *Anogeissus leiocarpus* and *Combretum hartmannianum*, and major grasses such as *Setaria pallidifusca*, *Hyparrhenia confinis*, *Loudetia togoensis* and *Schoenefeldia gracilis*,

(3) Semi-deciduous thorn woodland and wooded grassland on cracking clay plains with *Acacia seyal*, *Balanites aegyptiaca*, and *Dichrostachys cinerea* dominant in the woody component. In areas of lower rainfall *Acacia mellifera* may replace *Acacia seyal* as the dominant species),

(4) mixed deciduous wooded grassland on non-cracking clay plains with species similar to the footslopes but including trees like *Lannea humilis*, *A. gerrardii*, *Terminalia laxiflora*, and *Diospyros mespiliformis*, with



grass covering being more patchy in distribution,

(5) mixed deciduous and evergreen woodland (dominated by *Anogeissus leiocarpus*, *Tamarindus indica*, and *Acacia species.*) and wooded grassland on alluvial soils with trees such as *Faidherbia albida*, *Ficus species.* and *Piliostigma reticulata*, and grasses like *Pennisetum ramosum*, *Chloris species.* and *Cynodon dactylon*. In addition, swamp grasslands on seasonally flooded clay depressions are dominated by *Echinochloa* and *Oryza species...*

The 600-800 mm/annum rainfall zone vegetation on cracking and non-cracking clays is similar to that described above. As rain fall exceeds 500 mm/annum. cracking clays are liable to periodic flooding and grasses such as *Hyparrhenia rufa*, *Setaria incrassata* and *Andropogon gayanus* become more common. Trees on the non-cracking clays are better developed and show greater diversity in composition. Cracking clays subject to pronounced seasonal flooding, such as along Bahr el Arab drainage network, are characterized by tall grasses such as *Echinochloa pyramidalis*, *E. stagnina*, *Oryza spp.*, *Vetiveria nigritana*, and *Cyperus spp.*, with *Setaria* and *Hyparrhenia spp.* along the swamp fringes. Mixed deciduous and evergreen riparian woodland is found locally outside the flooded regions.

(6) The Baggara and Regeba Repeating Patterns contain aspect of many of the vegetation types described since their soils are similar to those found elsewhere. However, the vegetation, on these repeating soil patterns should be considered distinct from other vegetation types, because of their unique alternating pattern of soils and vegetation which are closely interrelated.

## **Chapter IV**

### **Materials and Methods**

#### **4.1 Data source**

The data used in this study is part of the data of the National Forest Inventory (NFI) which was conducted between March 1995 and July 1997. It was carried out by the Forests National Corporation (FNC) in collaboration with the Food and Agriculture Organization of the United Nations (FAO). The inventory, being the largest in scale in Sudan, provided an excellent baseline data for monitoring environmental changes, forest areas, tree species and forest products in the country. And AFRICOVER data as land cover classification from landsat image in same period of national forest inventory 1995-1997 was available. It was carried out by the Food and Agriculture Organization of the United Nations (FAO).

#### **4.2 Forest Inventory Based on Ground survey Method (NFI)**

The inventory design was flexible enough to combine with more detailed inventories, such as the national parks survey, or be used as a working model for regional inventories. The field work was done in 1995 and 1996, following a 1994 methodology preparation stage and staff training sessions in early 1995. Only ground plots were selected as saving on both costs and time. The lack of current inventories and current base maps (the available maps dated back more than 40 years), were further constraints. The inventory covered 627 sampling plots representing some of 6.27 million hectare in the Study area (Southern Darfur State). They are typical dry grassland and savannah zones, which would not be considered forest land under the FAO definition that sets the tree cover threshold at

10 percent. The inventory project was based on the measurement of fixed area plots on a systematic grid throughout the inventory area. The use of the GPS units meant that the sampling locations could be mapped using their co-ordinates without reference to any base mapping.

The sampling grid used was 10 km by 10 km with a field plot being established at each grid intersection. The plot size used was 20 by 100 meter, with an east/west orientation, the same as the SRAAD projects. This type of plot had been used in most inventories in the Sudan since 1983, and the FNC field staff was familiar and comfortable with this plot design (Groupe Poulin, 1984; Vink, 1987; Anonymous, 1990a, 1990b; Vogt, 1994). Rectangular plots are more difficult to accurately establish than circular plots, however, and so the latter would have been preferable. A number of data categories were devised as follows, each corresponding to multiple choice questions, excepting the items slope percent and aspect and year of felling

- Land use: forestry, grazing, cultivation, population centers, other;
- Land cover: trees, shrubs, grass, barren or water;
- Land condition: eroded, flooded, wind erosion (drifting or scouring), water erosion (rill, sheet or gully erosion, pedestalled plants), or no damage.
- Soil type: sandy, rocky, clay, loamy, dune, alluvium or sandy-clay;
- Landform: dune, wadi (water-course), mountain (uneven-height mountains), khor or no features;
- Slope percent and aspect;
- Origin of any trees: natural, plantation;
- History of harvest: clear-cut, partial cut, cleared or no cutting;
- Year of felling.

All trees or shrubs in the plot with a root collar diameter greater than five cm were tallied. Each plant was recorded as to species, live or dead, root collar diameter, total height, crown diameter measured at right angles to the plot's long axis, diameter at breast height, bole height and percent of cull. Shrub measurements were only taken in accordance with form and accessibility. The species and number of stems in it were tallied for all woody plants with a height greater than 15 cm and less than 130 cm.

The field data was entered into two databases, one for the plot observations, and one for the tree measurements. Plot location information which included the 1/250 000 map sheet references, the Universal Trans-Mercator (UTM) co-ordinates and the administrative region were added to the plot file. The information in these databases combined with volume equations were used to produce a summary database which included statistics for each plot. This plot summary file was used to produce aggregations of area or other criteria.

#### **4.3 Forest Inventory Based on Landsat image Interpretation Method**

The preparation of the study products relies essentially on remote sensing data and Geographic Information Systems (GIS). The land cover is mainly derived from visual interpretation of recent (1997) high-resolution satellite images digitally enhanced. It is done according to a homogenized and hierarchical classification system, the FAO Land Cover Classification System (LCCS), the classes of land cover created as following: Interpretation is digitized directly on screen on digital images (path 176,177,178 and row 51, 52, 53).

Edge matching, Mosaicing and Quality control was performed on the digital data. One mosaic of the study area was produced from the digital Scenes which is topologically corrected and

geographically projected.

Other GIS Functions such as polygon dissolve and Aggregation were, used to create classes according to the vegetation life form and density.

#### **4.4 Analysis**

All data was entered in a computer using dbase III plus programs and it was revised and compared with information on the hard copy. The data was then analyzed and mapped using dbase III plus, excel, ARCINFO and ARCVIEW software's. ARCINFO and ARCVIEW were software's that used for Geographical Information System (GIS) analysis and mapping.

The following analysis were performed

- a) Dbase III plus program was used for adding all tree and shrub found in a plot then calculating volume per hectare by multiplying the total volume of plot by 5 ( the sample plot area = 0.2 ha ), and also for stems. The equation and program used for stems and volume calculation see (Annex 2).
- b) GIS Analysis function summary file for each quarter million sheet were used to determination plot location, plot No., volume/ha, Crown closure/ha and number of stems/ha.
- c) Arc/info & Arc view software were used to plot the following maps: densities of trees, crown closure, land cover and land use for ground survey and land sat image, and using
- d) GIS query builder for the combination Analysis at the obtained results form ground survey and from landsat image Analysis.

## **Chapter V Results and Discussion**

The results are presented according to land cover and land use that obtained from ground survey and from landsat images interpreter. The results summarize the areas of each class and its relative frequency compared to other classes.

The tables below show the area of Landover/ land-use by ground survey and by Landsat image interpretation and combined on integrated Analysis of results using GIS Techniques provides better estimated of forest average volume /ha, average crown closure % /ha, and average stems-number/ha .

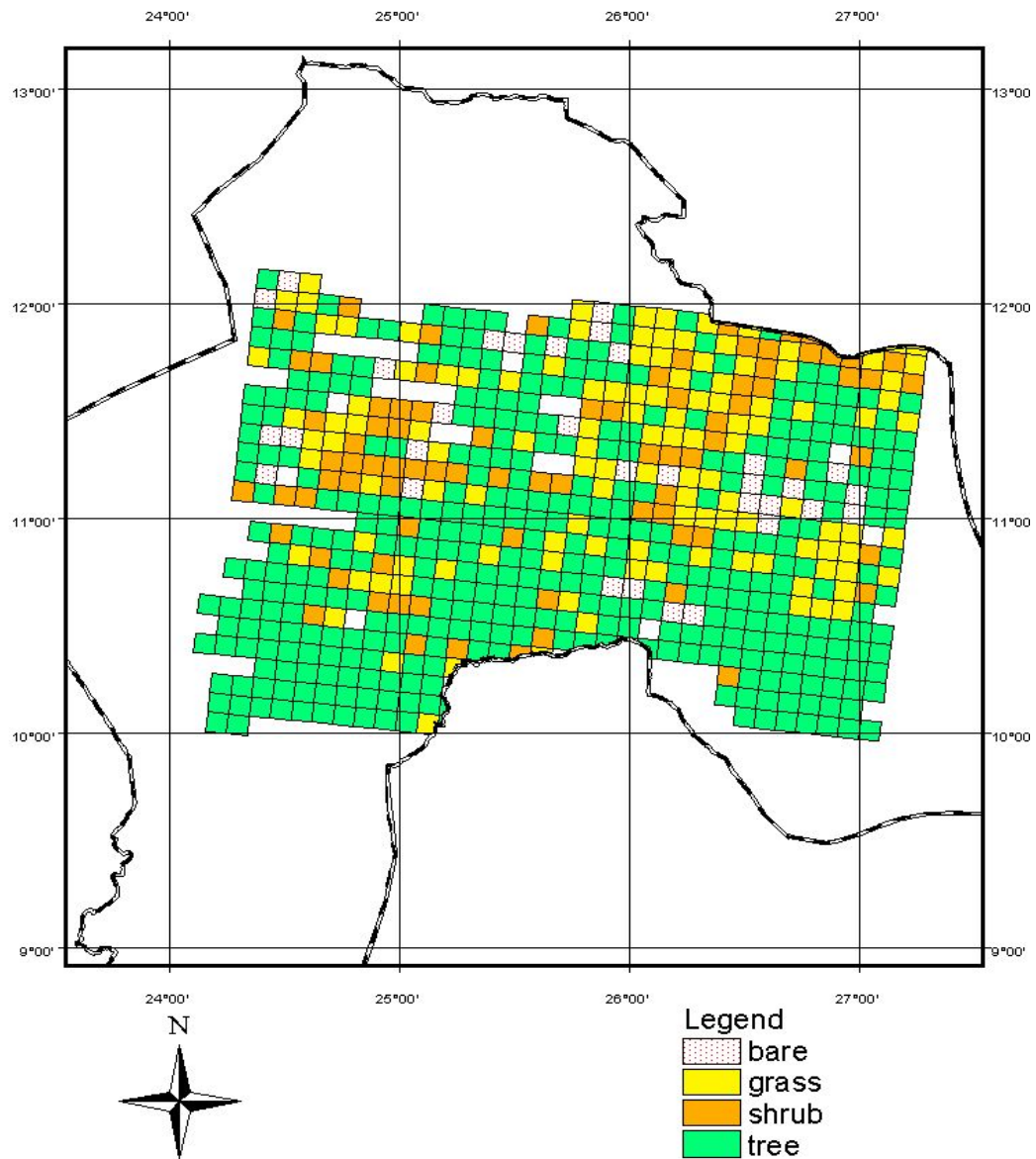
### 5.1. Land Cover

The area covered by tree and shrub according to ground survey was found to be (4 487 129 ha). Table (5.1) and figure (5.1) show the details of the land cover and the tree distribution according to the NFI (1996)

Table (5.1) Land covers area according ground survey (NFI, 1996)

land cover	area in hectares
bare	320 000
grass	1 179 159
shrub	803 728
tree	3 683 401
total	5 986 289

Figure 5.1 land cover classes according to ground survey (NFI, 1996)



When land sat image for the same year and season were used, the area covered by trees and shrubs was found to be (3 872 735 ha), Table (5.2)

and figure (5.2) give details about the different land cover types and the tree distribution according to landsat image taken in the year 1996.

Table (5.2) Land covers area according to landsat images (1996}

Land cover	area in hectares
bare	3 551
grass	2 110 003
shrub	1 495 780
tree	2 376 955
total	5 986 289



Figure 5.2 land cover classes (landsat TM images, 1996)

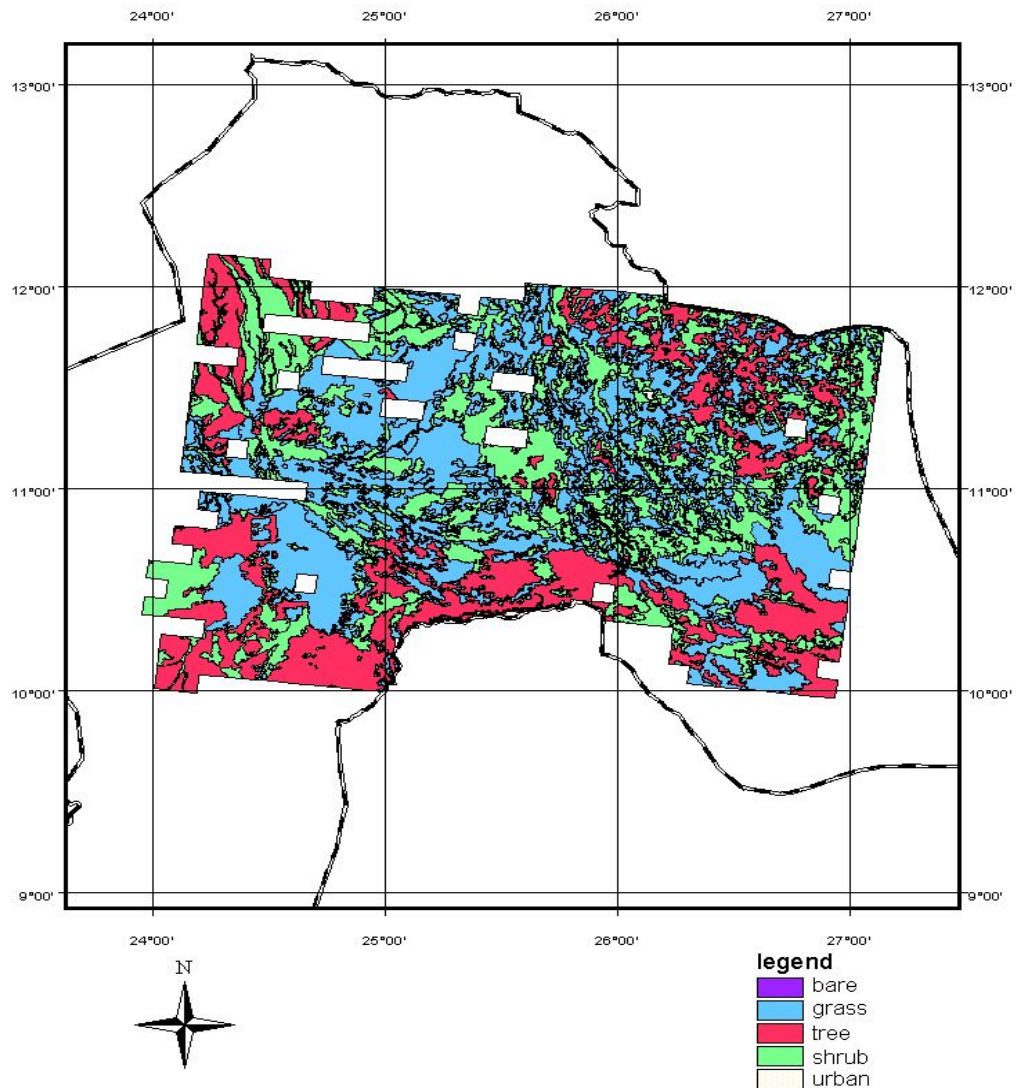
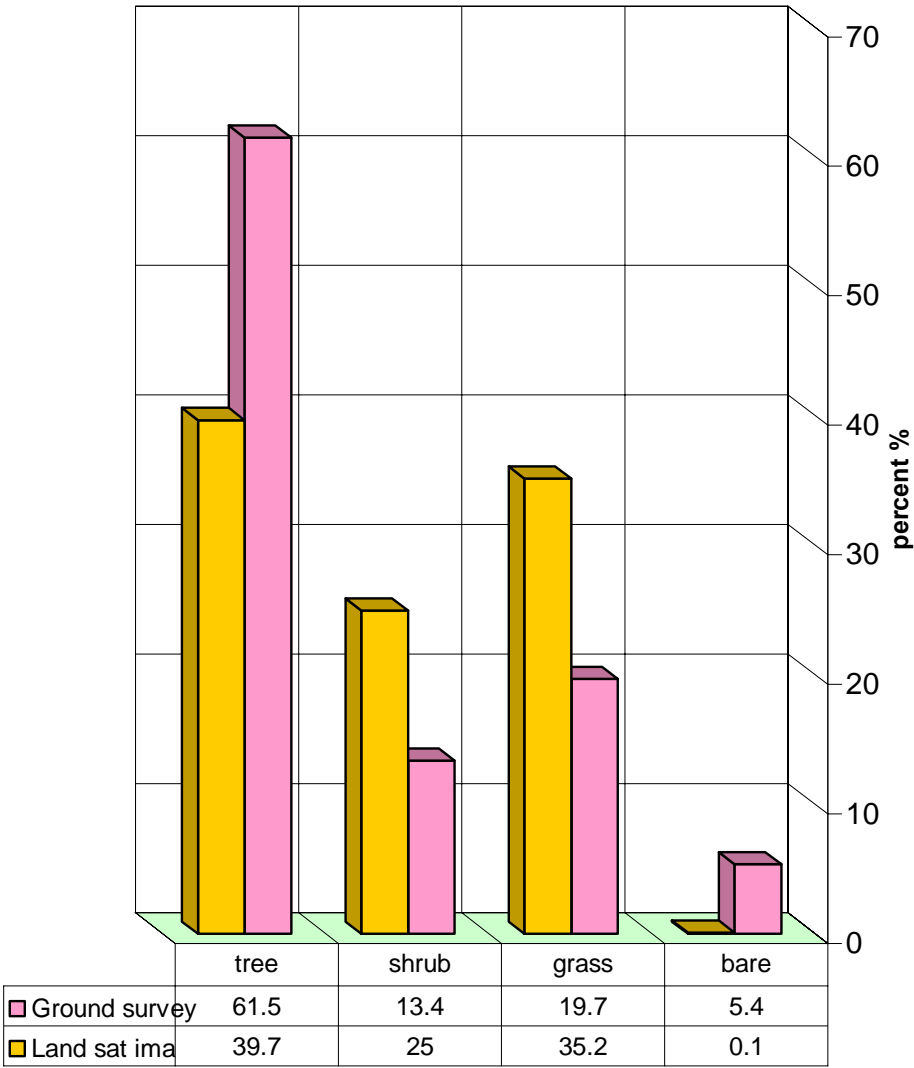


Table (5.3) (see Annex1) and Figure (5.3) shows that the area covered by vegetation is higher according to ground survey method than land sat method with 13.7%. Figures (5.1) and (5.2) show the trees distribution on the Study area by Ground Survey and Landsat image

Figure 5.3 comparison of land covers according to ground survey and landsat images in percent



The land cover comparison as in table (5.3) (see Annex1) and figure (5.3) show that the area covered by trees in the ground survey method is greater than that of land sat imagery. The ground survey defines sample plot as trees cover and that sample plot represents a square of 10 X 10 km was calculated as trees area, while land sat image for the same plot considers only the area covered by trees. The cover was then calculated by determining the area of trees from the image.

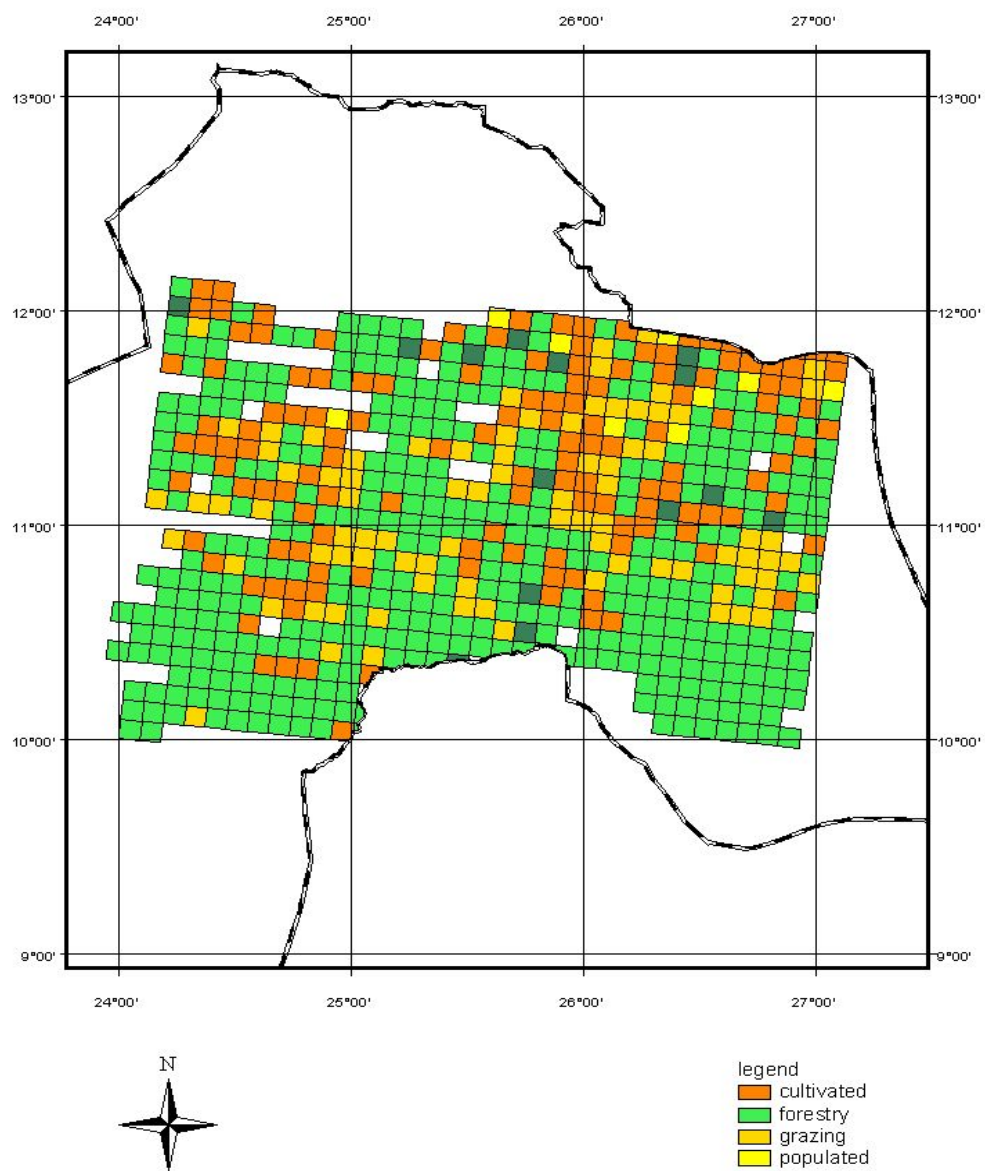
## 5.2 Land Use

Land use is characterized by the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it. The area used by forestry according to ground survey was found to be (3 583 788 ha). Table (5.4) and figure (5.4) show the details of the land use according to the NFI (1996)

Table (5.4) land use area by ground survey

land use	area in hectares
cultivated	<b>1 328 139</b>
forestry	<b>3 583 788</b>
grazing	<b>856 180</b>
urban	<b>85 624</b>
unknown	<b>231 557</b>
Total	<b>5 986 289</b>

Figure 5.4 land use classes according to ground survey (NFI, 1996)



When land sat image for the same year and season were used, the area used by forestry was found to be (2 480 247 ha).Table (5.5) and figure (5.5) give details about the different land use types according to land sat images taken in the year 1996.

Table (5.5) land use area according to land sat image

land use	area in hectares
bare	3 549
cultivated	2 364 293
forestry	2 480 247
grazing	1 129 405
urban	8 795
total	5 986 289

Figure 5.5 land use classes according to landsat images,1996

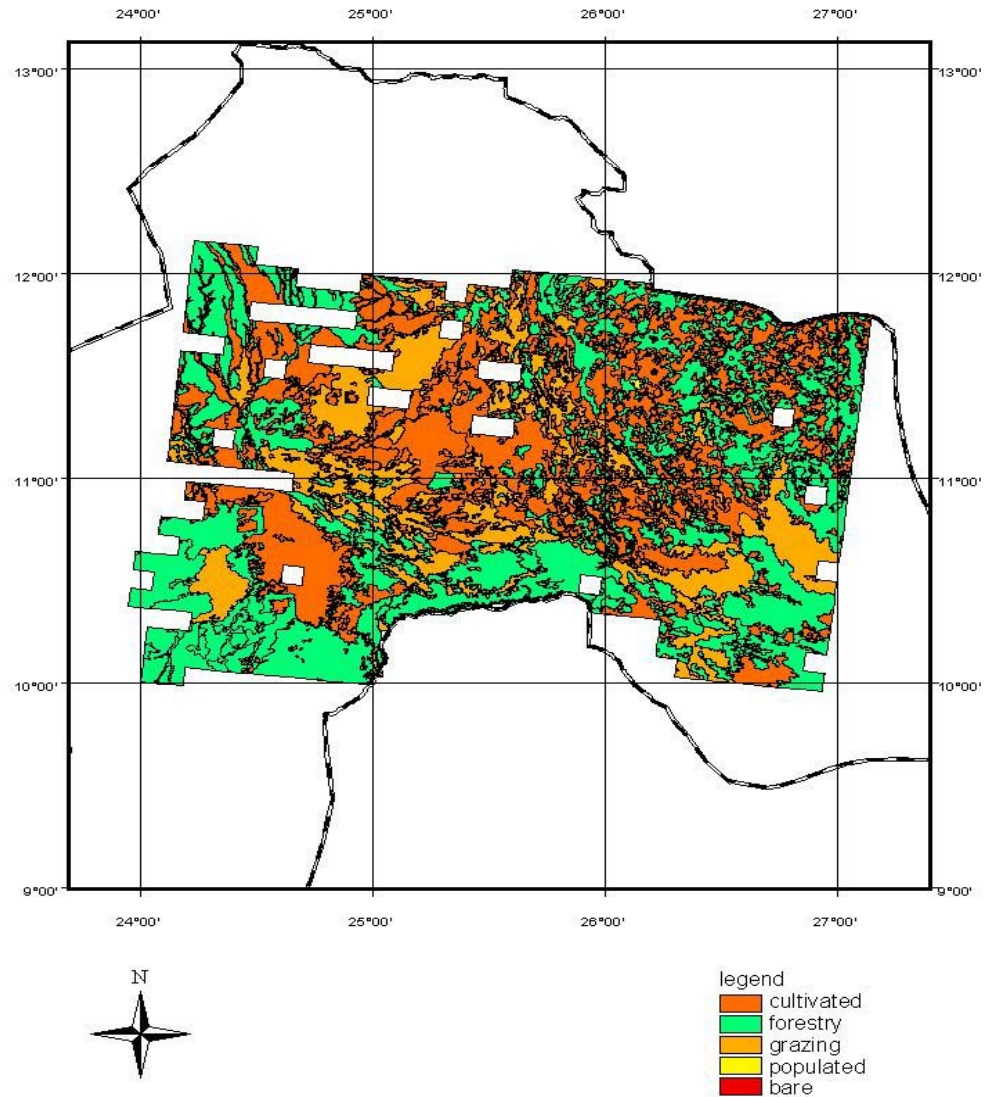
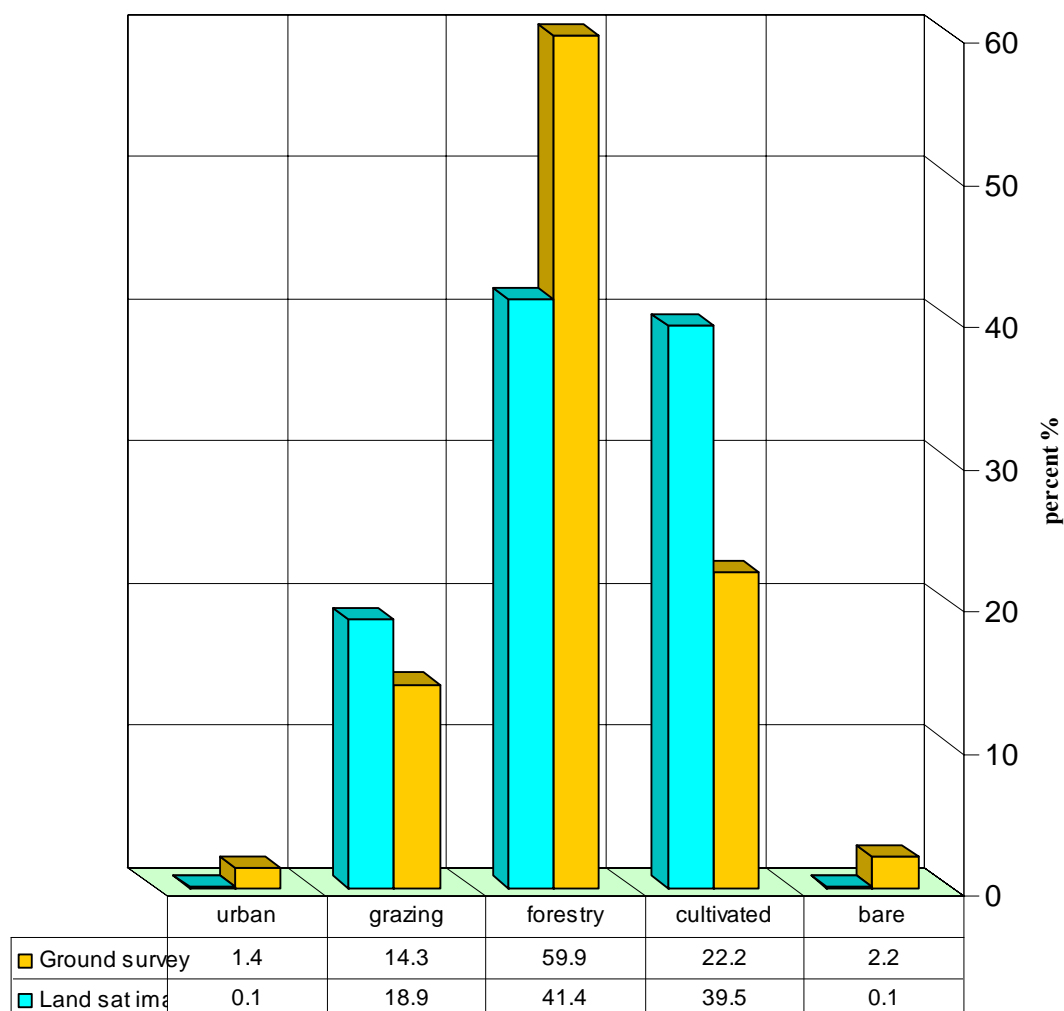


Table (5.6) (see Annex1) and figure (5.6) show area of land use classes in percentage by ground survey and land sat images .The ground survey over estimates the forest area by 18.5%.

The land use comparison as in table (5.6) (see annex1) and figure (5.6) indicate that the forest area in the ground survey method is greater than that from land sat images.

Figure 5.6 comparing land use classes according to ground survey and landsat images



### 5.3 Combination of ground survey and land sat image

The result of combination through GIS databases and detailed remote sensing can provide improved, consistent, and accurate measures of forests crown closure, volume and stems/ha, and estimate of land cover/use.

### 5.3.1 Crown Closure

The area of forest by using FAO's definition according to ground survey was found to be (1 629 036.5 ha). Table (5.7) and figure (5.8) show the area of crown closure greater than 10%, according to the NFI (1996). When combining land sat images, and FAO's definition with ground survey. The area of forest was found to be (1 660 686.5 ha). Table (5.7) and figure (5.9) show the area of forest crown closure greater than 10%, according to the land sat image (1997). The difference was found to be 31650 hectares

Table (5.7) Total area of forest  $\geq 10\%$  and its results

land use	area in ha	Average crown closure%/ha	Average volume m <sup>3</sup> / ha	Average stems/ha
Forest in ground survey	1 629 036.5	15.2	8.45	86
Forest in combination of g. survey & landsat image	1 660 686.5	16.5	8.55	97

The ground survey alone underestimates the area covered by forest (crown closure  $\geq 10$ ) (table 5.7, figure 5.7, 5.8) .On the other hand there are only slight difference between calculated volumes, crown closure and number of trees per ha when comparing between results from ground survey alone and combination of ground survey and landsat images.



Figure 5.7 forest crown closure (crown coverage  $\geq 10\%$ ) according to ground survey

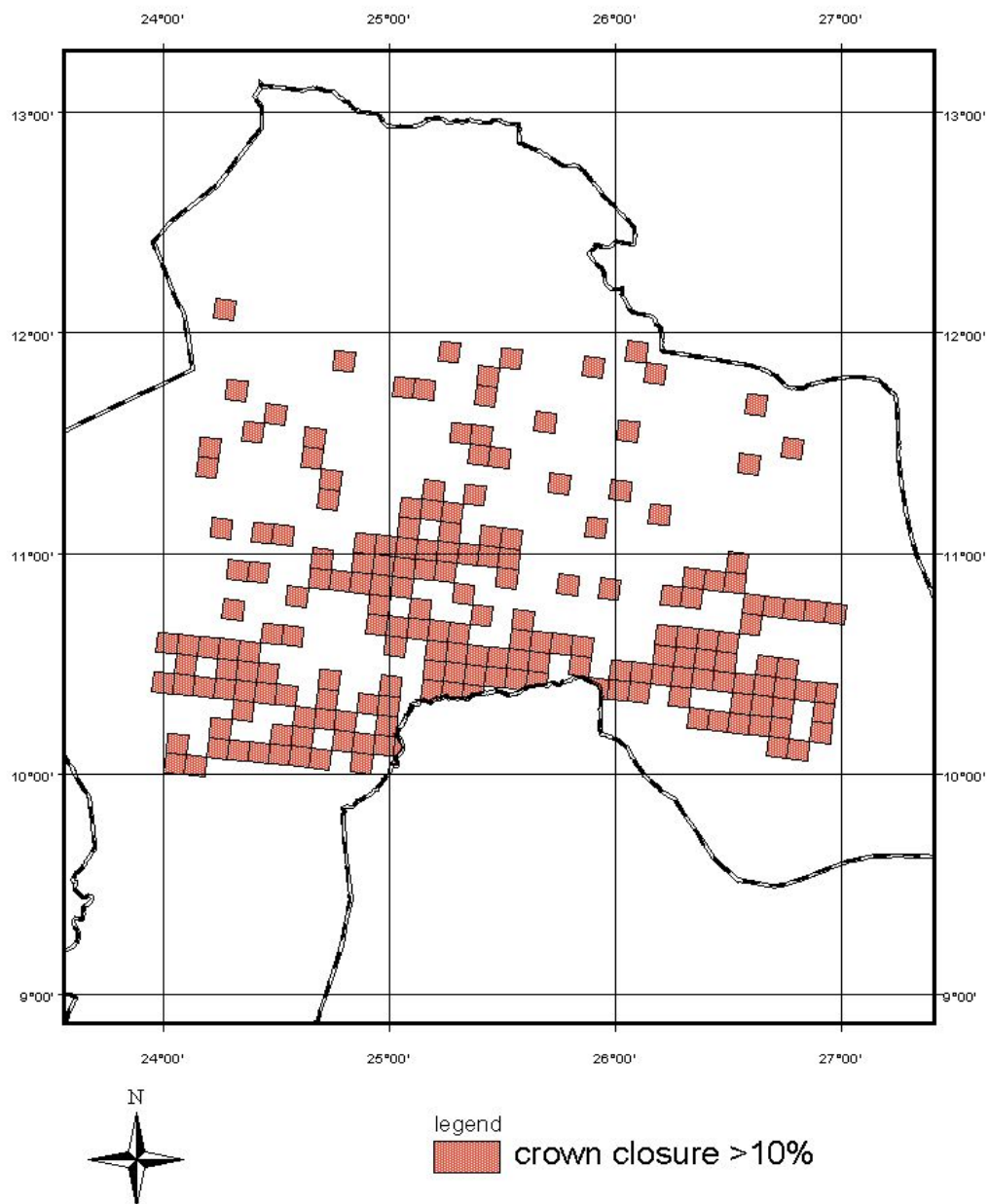
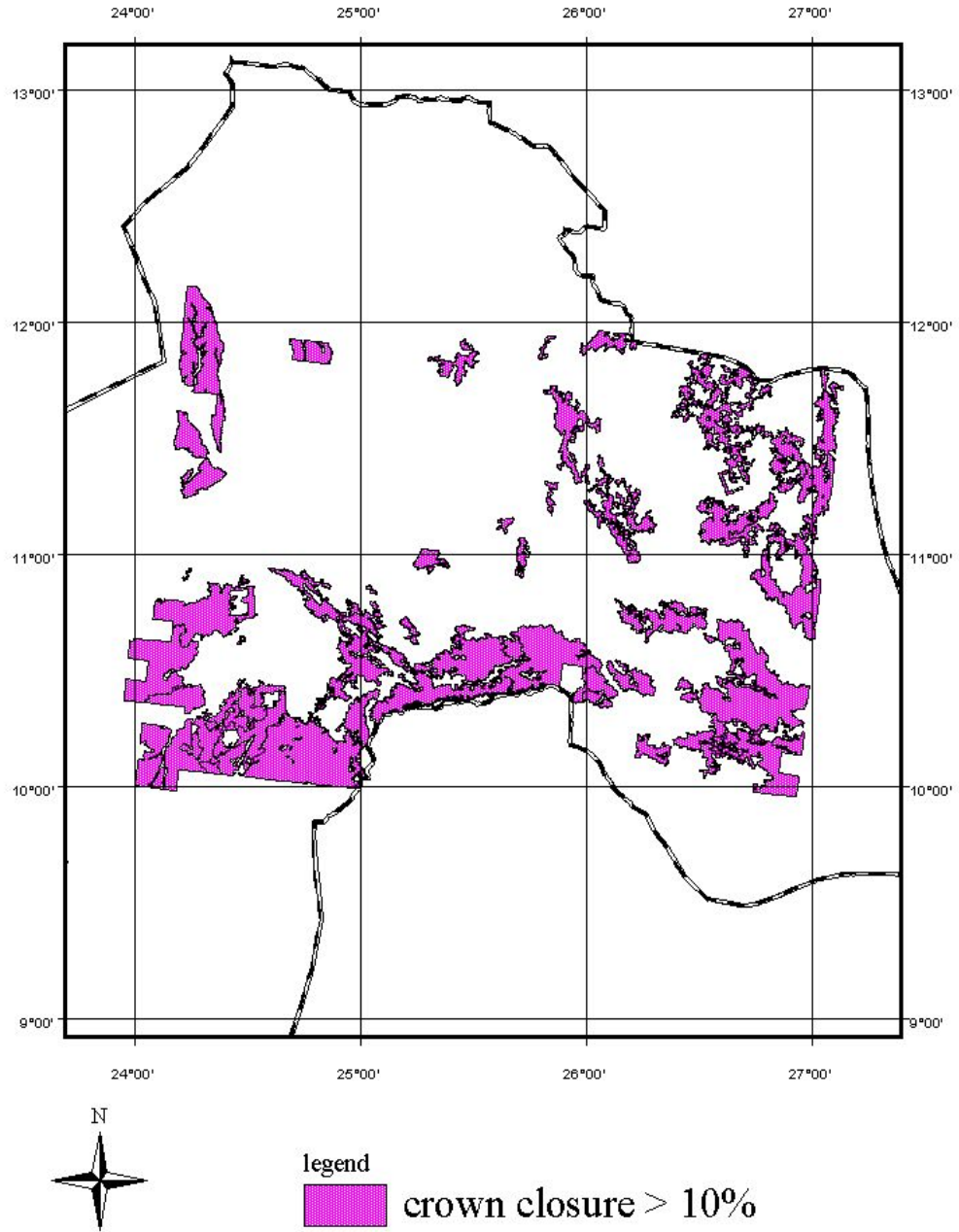


Figure 5.8 forest crown closure (crown coverage  $\geq 10\%$ ) according to landsat images



### 5.3.2 Volume

The calculation of wood volume according to ground survey was found to be (28 562 790 m<sup>3</sup>). Tables (5.8, 5.10) and figure (5.8) show the volume by diameter at root collar (DRC) according to the NFI (1996). The calculation of volume for combination of land sat and plot of ground survey was found to be (21 196 438 m<sup>3</sup>).The difference was 7181916 m<sup>3</sup>/ha

Table (5.8) total area of forest in (ha) and volume in (m<sup>3</sup>) according to ground survey and combination of ground survey and landsat images

Land use	total area in hectares	total volume m <sup>3</sup>
ground survey	3358385	28378353
Combination of ground survey & landsat image	2480247	21196438

Tables (5.9) and (5.10) (see annex1) provide details on the volume and stems number of the trees found by species and size class for all study area, and figures (5.9), (5.10) show the volume and number of stems for all tree, the bulk of the volume and number of stems per hectare in the inventory area was found in small dimensions.

Figure 5.9          volumes in m<sup>3</sup>/ha by diameter classes (DRC)

according to ground survey

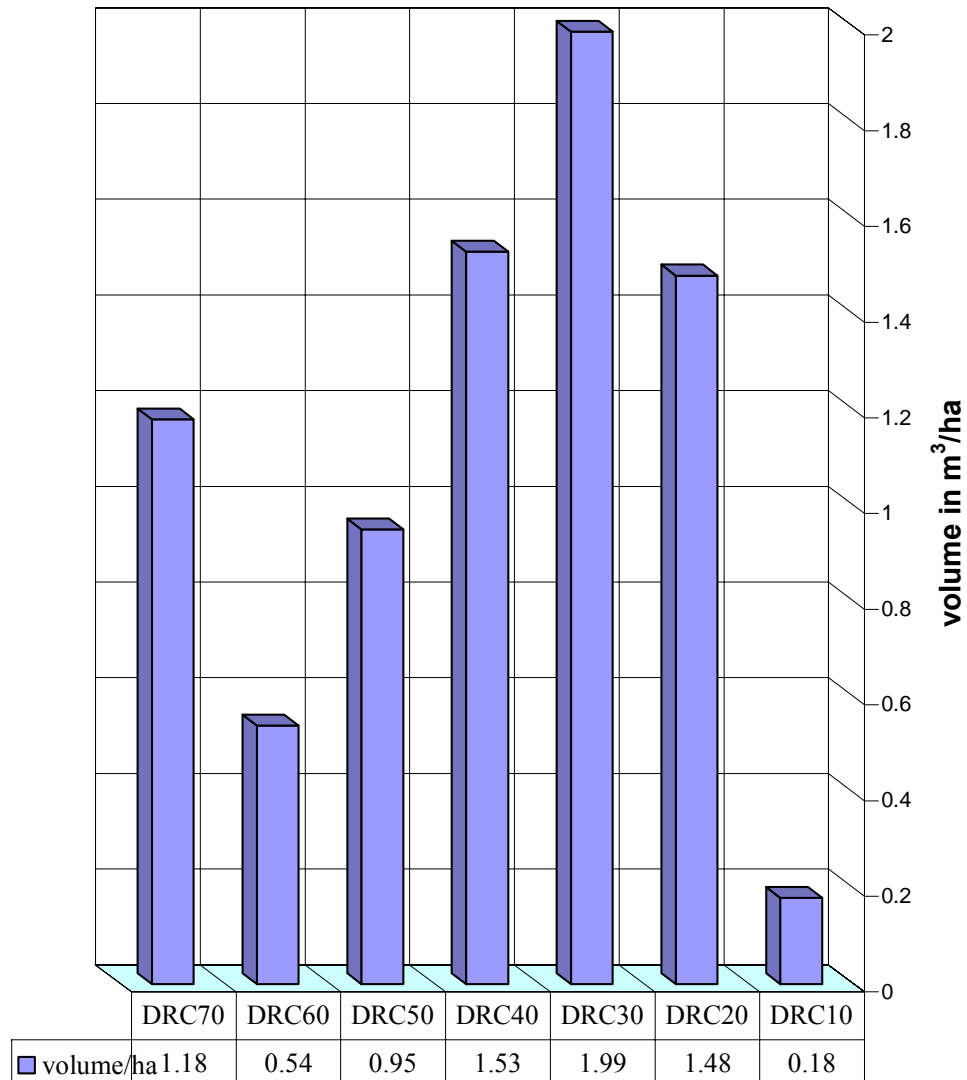
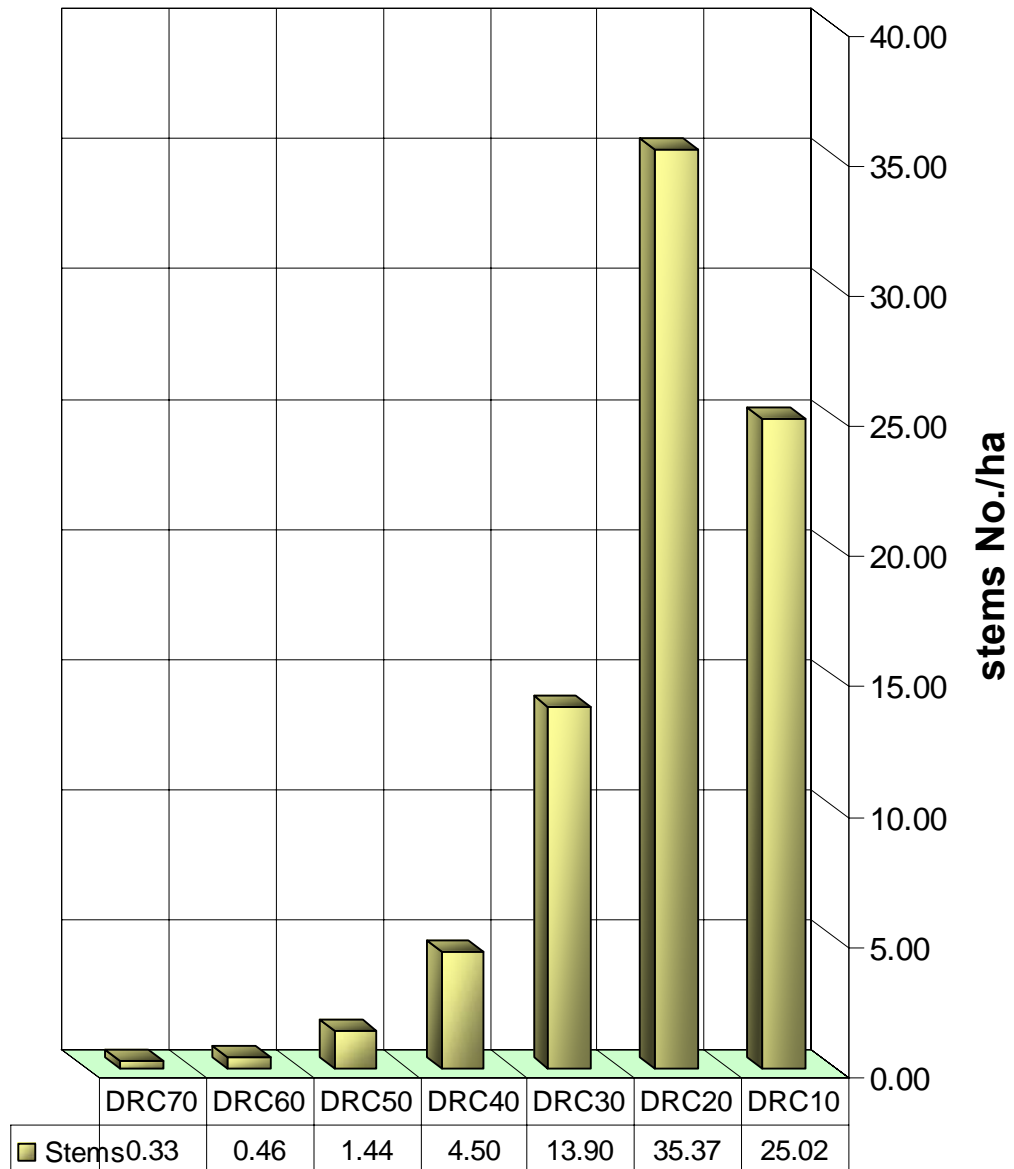


Figure 5.10 numbers of stems/ha by diameter classes (DRC)



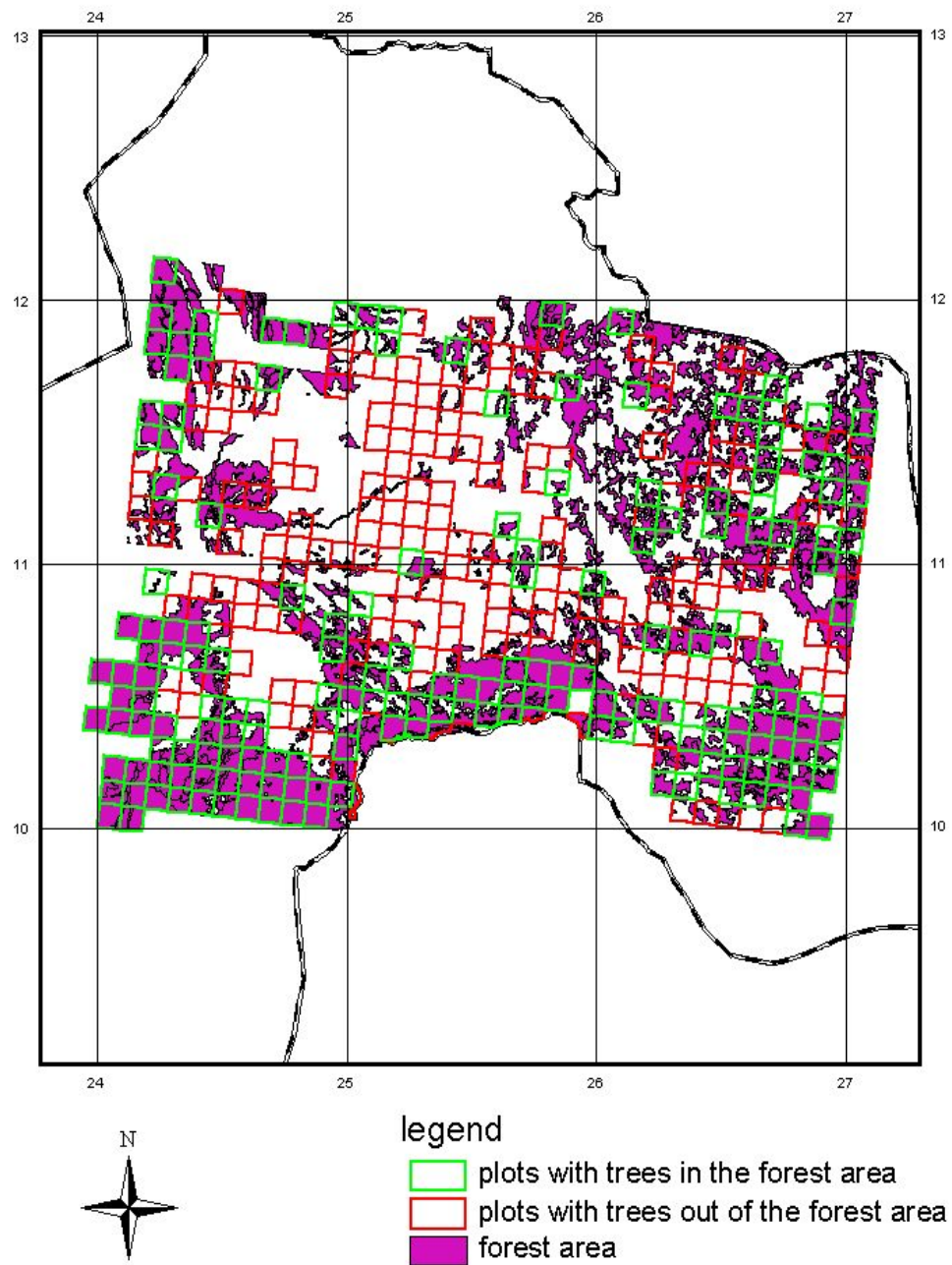
### 5.3.3 Improving of land cover (trees and shrubs)

The number of sample plots laid out by ground survey was greater than the sample plots on the land sat images after delineation .About half of the sample plots were needed, for land cover trees and shrubs. Table (5.11) and figure (5.11) show the details of sample plots.

Table (5.11) comparing sample plots according to ground survey and landsat TM images

Land cover (tree and shrub)	plot no
Ground survey	450
Land sat image	200

Figure 5.11 trees and shrubs area according to ground survey and landsat TM images





### 5.3.4 Improving number of sample plots containing trees as land use

The area used as forest in the study area according to ground survey was represented by 340 sample plots table (5.12) of 0.2 ha each .As the area of forest was delineated in the land sat images of the study area ,only 169 sample plots were sufficient to give similar results (table 5.12) . This indicates that combining ground survey and land sat images help in reducing the number of sample plots needed, and hence reducing the inventory expenses (time and money

Table (5.12) Number of sample plots used by ground survey and combination method, and result of land use classes

land use	plot no		average volume m3/ha		average crown closure %		no. of stems/ha	
method	ground survey	Combination	ground survey	Combination	ground survey	Combination	ground survey	Combination
forest	340	169	8.1	8.6	14.6	15.7	81	169
cultivated	89	50	1.5	2.8	3.7	3.8	27	50
grazing	132	70	2.1	0.9	2.8	2.4	17	70

The plots measured that included trees were not classified as forests. This shows that considerable numbers/volume of trees is in grazing or in particular cultivated areas. Table 5.12 and figures (5.12, 5.13, 5.14 and 5.15) shows the details of the results for each land use class containing trees.

Figure 5.12 plot numbers of ground survey only and combination of ground survey and land sat image

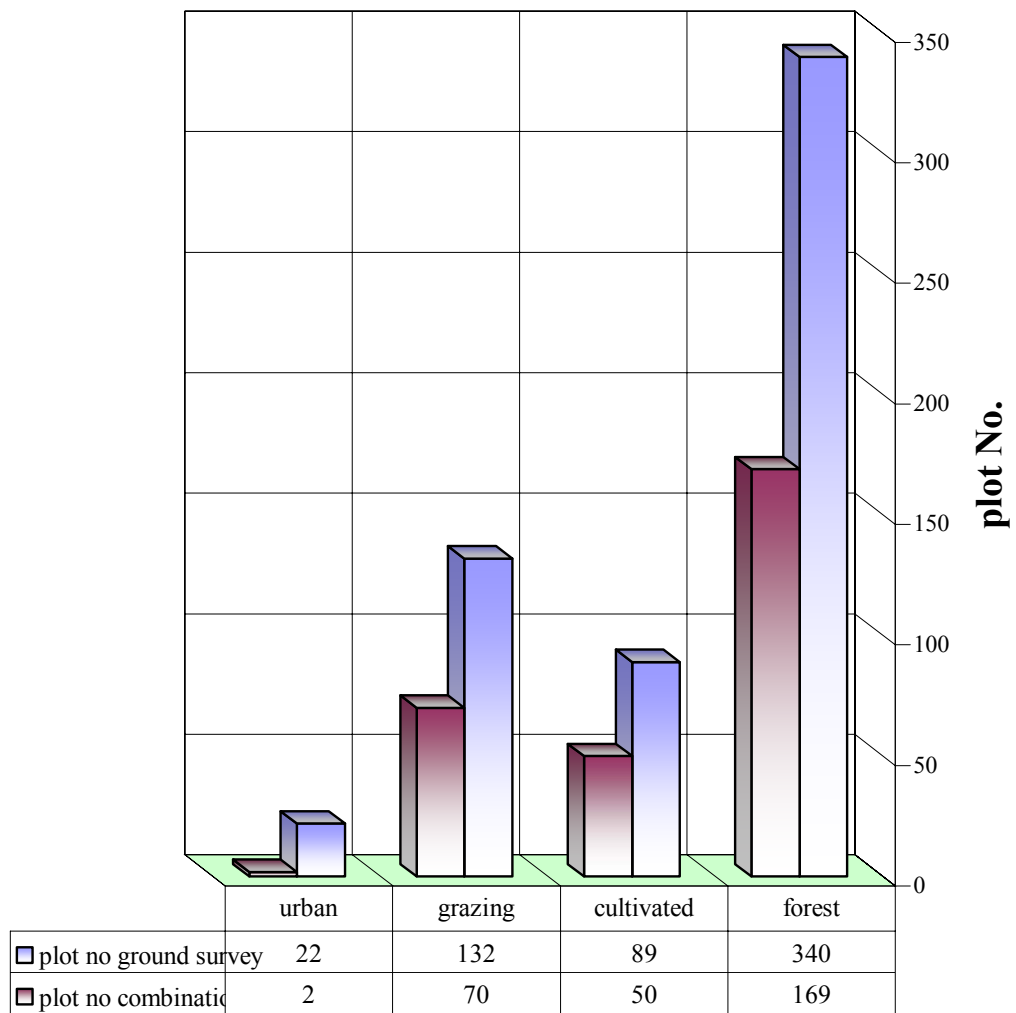


Figure 5.13 volumes in m<sup>3</sup>/ha for ground survey only and combination of ground survey and land sat image

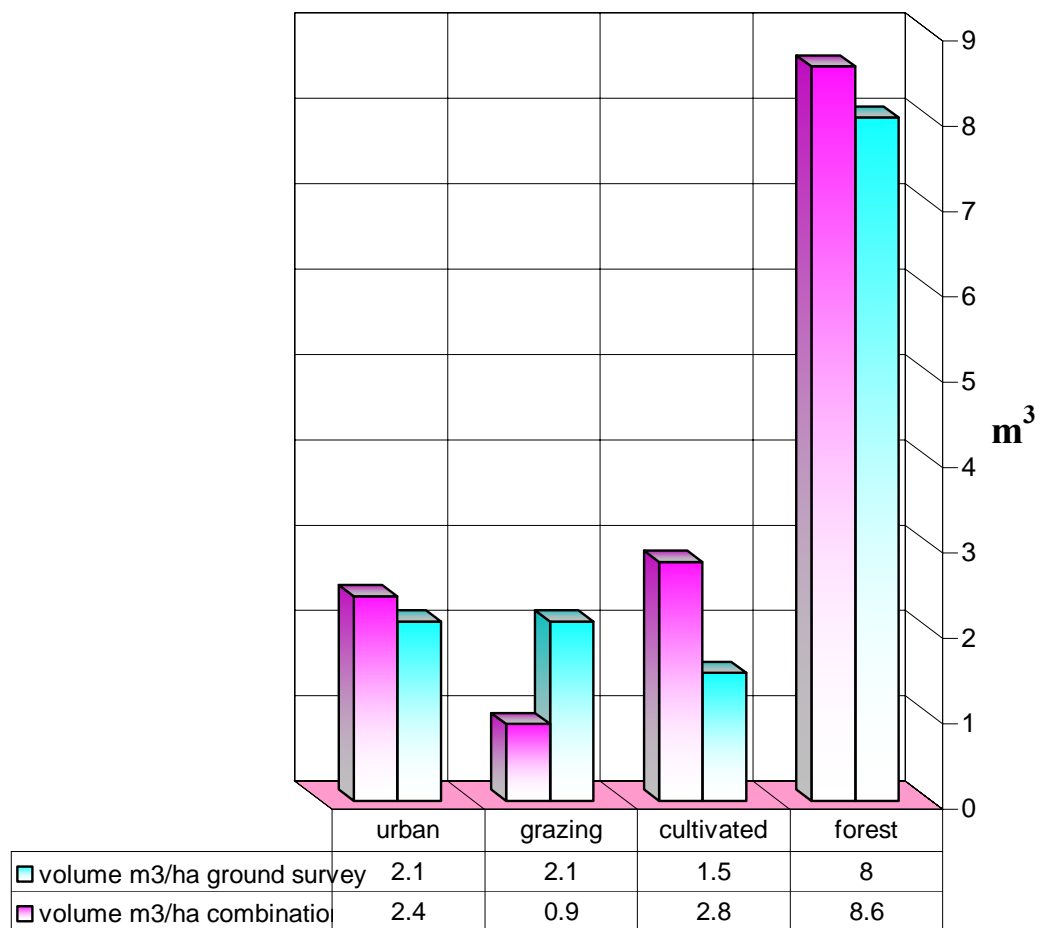


Figure 5.14 crown closure percent/ha for ground survey only and a combination of ground survey and landsat TM image

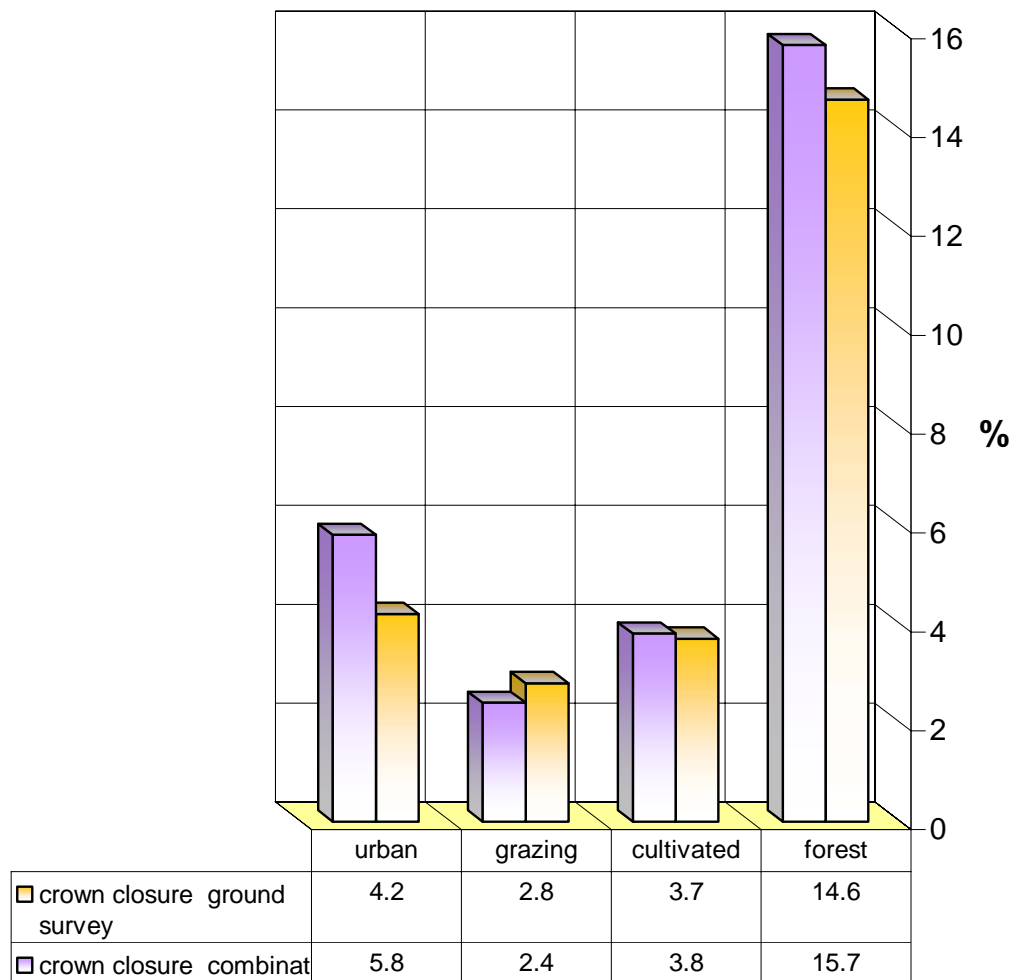
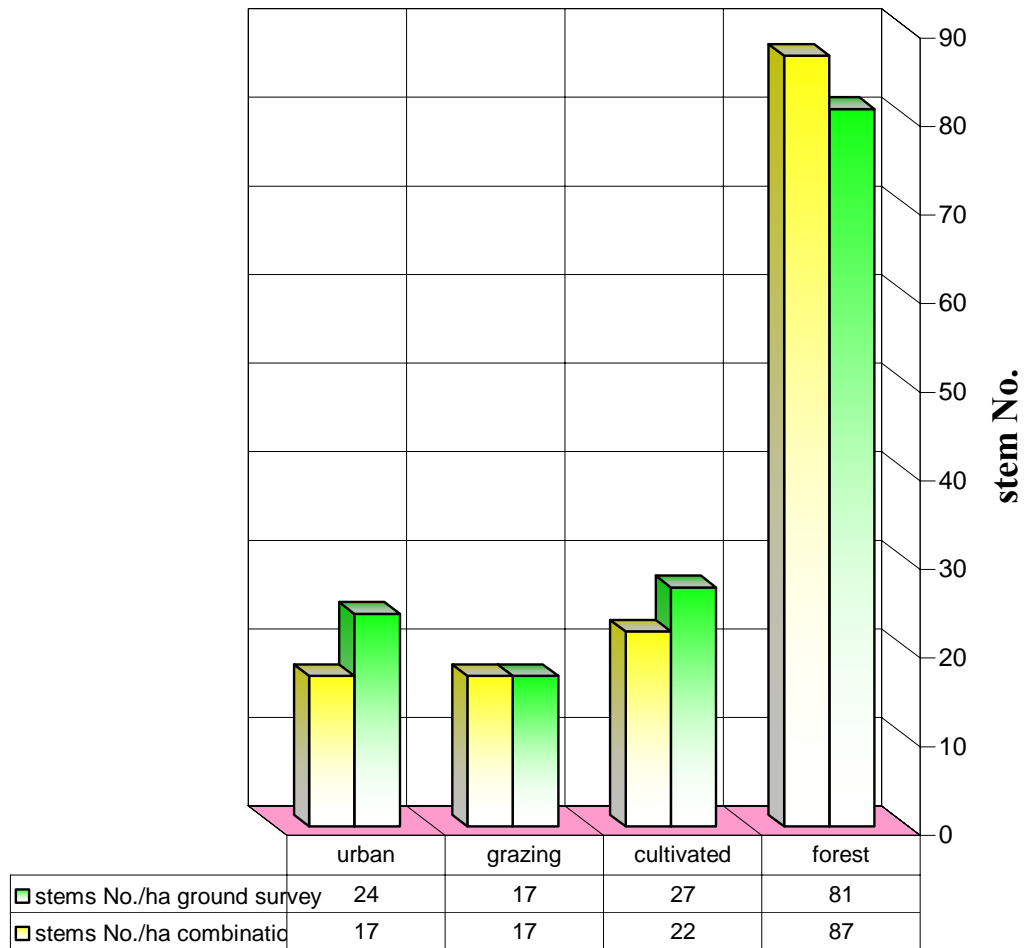


Figure 5.15 stem number/ha for ground survey and combination of ground survey and landsat TM image



## **Chapter VI**

### **Conclusions and Recommendations**

#### **6.1 Conclusions**

The area covered by woody vegetation is higher according to ground survey method than landsat method by 13.7%.

The area used by forests is higher according to ground survey method than landsat method by 18.5%.

The comparison of land cover and land use for the two methods show that the ground survey only gives overestimations, for its low intensity, and hence misleading result are drawn.

The landsat image method gives information about the determination of forest area, and not details of the forest main parameters like crown closure percentage, volume and number of stems per hectare, while the resolution of the land sat images does not allow distinguishing the details.

Therefore the combination of ground survey and remote sensing images is more effective to be used in future national forest inventories, because it reduces the number of sample plots to be laid out , reduce efforts, time and money expended, in forest inventories

## **6.2 Recommendations**

It is recommended that:

- 1- The results from this study will be used to improve the spatial distribution and quality of the rest of the national forest inventory, so as to reduce expenditure and achieve more accurate results.
- 2- To apply the combined method of ground survey and landsat imagery during the inventory of southern Sudan after the end of the civil war there.
- 3- More work to be done in other areas of the NFI.

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### **Annex.1**

Table (5.3) comparison of land covers according to land sat images and ground survey in percentage

land cover	Ground survey	Land sat image.
bare	5.4	0.1
grass	19.7	35.2
shrub	13.4	25
tree	61.5	39.7

Table (5.6) comparing area of land use classes in percentage

land use	Ground survey (%)	Land sat image (%)	Difference
bare	2.2	0.1	2.1
cultivated	22.2	39.5	17.8
forestry	59.9	41.4	18.5
grazing	14.3	18.9	4.6
urban	1.4	0.1	1.3

Table (5.9) Stock table

SPECIES	DRC10	DRC20	DRC30	DRC40	DRC50	DRC60	DRC70	TOTAL
ABANOUS	0.00	0.06	0.06	0.05	0.04	0.00	0.00	0.23
ABUELSIROJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ABULELA	0.00	0.01	0.01	0.01	0.02	0.00	0.00	0.06
ABUNDAGIG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
ABUNGAWI	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ABUSIROG	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.06
ANDARAB	0.00	0.01	0.01	0.01	0.00	0.00	0.30	0.33
ARAD	0.01	0.06	0.19	0.19	0.15	0.04	0.07	0.71
ARADEIB	0.00	0.00	0.01	0.04	0.02	0.05	0.14	0.27
ARIG	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01
BAKISA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DAROUT	0.00	0.08	0.20	0.08	0.05	0.00	0.00	0.41
DOAM	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
DURUBA	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01
GAFAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
GAIRLY	0.00	0.02	0.04	0.05	0.01	0.00	0.00	0.12
GOBBEISH	0.02	0.03	0.01	0.01	0.00	0.01	0.00	0.08
GODIEM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HABEIL	0.04	0.17	0.21	0.16	0.04	0.00	0.00	0.63
HARHAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HASHAB	0.01	0.12	0.11	0.02	0.01	0.00	0.00	0.27
HEGLEIG	0.00	0.04	0.16	0.20	0.14	0.11	0.07	0.73
HUMIED	0.00	0.00	0.03	0.14	0.15	0.17	0.29	0.79
JOGHAN	0.00	0.00	0.00	0.02	0.02	0.00	0.02	0.06
KADAD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
KAKAMOUT	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.03
KHAROUB	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.02
KHASHKHASH	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01
KITIR	0.01	0.05	0.09	0.05	0.01	0.00	0.00	0.21
KUK	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.04

KULKUL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
LAUT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LAYUN	0.01	0.06	0.03	0.01	0.01	0.00	0.00	0.11
LUBAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MAHOGANI	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
MAYLEES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MILEAS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MIRFAAEN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
MUHAGREIA	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.04
MUKHEIT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SAHAB	0.00	0.02	0.10	0.15	0.21	0.10	0.04	0.62
SALGAM	0.01	0.06	0.08	0.05	0.01	0.01	0.00	0.22
SARIH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SEYAL	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.02
SHAJARMIRF	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHAJERSIM	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SHUBAHI	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.03
SIDIR	0.00	0.02	0.03	0.02	0.01	0.00	0.00	0.09
SUNT	0.00	0.01	0.02	0.02	0.01	0.00	0.00	0.06
TALH	0.06	0.44	0.32	0.13	0.02	0.00	0.00	0.97
TARAGTARAG	0.00	0.11	0.17	0.05	0.01	0.00	0.20	0.54
TUNDOB	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
UMBAKISA	0.01	0.04	0.02	0.00	0.00	0.00	0.00	0.06
UMHMEARON	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
UMMADIKA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UMSINANA	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
UMSINOON	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UMTAKARONA	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
USHAR	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
<b>TOTAL</b>	<b>0.18</b>	<b>1.48</b>	<b>1.99</b>	<b>1.53</b>	<b>0.95</b>	<b>0.54</b>	<b>1.18</b>	<b>7.97</b>

Table (5.10) Stand table

SPECIES	DRC10	DRC20	DRC30	DRC40	DRC50	DRC60	DRC70	TOTAL
ABANOUS	0.47	1.39	0.48	0.20	0.10	0.00	0.00	2.64
ABUELSIROJ	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
ABULELA	0.28	0.32	0.07	0.02	0.02	0.00	0.00	0.71
ABUNDAGIG	0.03	0.10	0.01	0.00	0.00	0.00	0.00	0.14
ABUNGAWI	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.06
ABUSIROG	0.03	0.03	0.10	0.07	0.00	0.00	0.00	0.23
ANDARAB	0.18	0.22	0.11	0.05	0.01	0.00	0.01	0.59
ARAD	0.76	1.46	1.32	0.56	0.22	0.03	0.03	4.38
ARADEIB	0.01	0.06	0.11	0.11	0.02	0.04	0.03	0.38
ARIG	0.00	0.02	0.03	0.01	0.00	0.00	0.00	0.06
BAKISA	0.05	0.07	0.00	0.00	0.00	0.00	0.00	0.13
DAROUT	0.47	1.37	1.24	0.21	0.06	0.00	0.00	3.36
DOAM	0.00	0.02	0.05	0.01	0.00	0.00	0.00	0.09
DURUBA	0.01	0.04	0.02	0.01	0.00	0.00	0.00	0.09
GAFAL	0.02	0.03	0.04	0.00	0.00	0.00	0.00	0.10
GAIRLY	0.07	0.39	0.23	0.13	0.02	0.00	0.00	0.85
GOBBEISH	3.40	1.10	0.13	0.04	0.01	0.01	0.00	4.69
GODIEM	0.06	0.10	0.00	0.00	0.00	0.00	0.00	0.16
HABEIL	5.01	4.31	1.53	0.48	0.09	0.01	0.00	11.43
HARHAR	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
HASHAB	1.84	3.15	0.93	0.10	0.01	0.00	0.00	6.02
HEGLEIG	0.33	1.15	1.09	0.64	0.24	0.11	0.05	3.61
HUMIED	0.02	0.02	0.16	0.31	0.19	0.13	0.09	0.91
JOGHAN	0.00	0.04	0.03	0.04	0.02	0.00	0.01	0.15
KADAD	0.27	0.09	0.00	0.00	0.00	0.00	0.00	0.35
KAKAMOUT	0.11	0.18	0.02	0.00	0.00	0.00	0.01	0.32
KHAROUB	0.45	0.36	0.03	0.03	0.00	0.00	0.00	0.87
KHASHKHASH	0.01	0.12	0.04	0.00	0.00	0.00	0.00	0.17
KITIR	0.81	1.67	0.88	0.27	0.03	0.00	0.00	3.66
KUK	0.01	0.05	0.02	0.02	0.01	0.01	0.00	0.13
KULKUL	0.02	0.09	0.02	0.00	0.00	0.00	0.00	0.13

LAUT	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.04
LAYUN	0.80	1.89	0.23	0.02	0.01	0.00	0.00	2.96
LUBAN	0.19	0.12	0.00	0.01	0.00	0.00	0.00	0.32
MAHOGANI	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
MAYLEES	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.02
MILEAS	0.04	0.01	0.03	0.00	0.00	0.00	0.00	0.09
MIRFAAEN	0.01	0.01	0.03	0.00	0.00	0.00	0.00	0.05
MUHAGREIA	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02
MUKHEIT	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.10
SAHAB	0.10	0.24	0.51	0.33	0.29	0.09	0.02	1.57
SALGAM	0.55	1.17	0.50	0.14	0.01	0.01	0.01	2.39
SARIH	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
SEYAL	0.02	0.11	0.10	0.00	0.00	0.00	0.00	0.22
SHAJARMIRF	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
SHAJERSIM	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
SHUBAHI	0.12	0.23	0.07	0.00	0.00	0.00	0.01	0.44
SIDIR	0.48	0.70	0.22	0.09	0.02	0.00	0.00	1.51
SUNT	0.18	0.18	0.15	0.07	0.01	0.00	0.00	0.60
TALH	5.81	8.94	1.95	0.38	0.02	0.00	0.01	17.11
TARAGTARAG	0.17	1.87	1.13	0.13	0.01	0.00	0.03	3.34
TUNDOB	0.03	0.09	0.05	0.01	0.00	0.00	0.00	0.18
UMBAKISA	0.98	1.22	0.15	0.01	0.00	0.00	0.00	2.36
UMHMEARON	0.55	0.21	0.01	0.00	0.00	0.00	0.00	0.78
UMMADIKA	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.03
UMSINANA	0.11	0.17	0.03	0.00	0.00	0.00	0.00	0.31
UMSINOON	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01
UMTAKARONA	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
USHAR	0.04	0.12	0.01	0.00	0.01	0.00	0.00	0.18
<b>TOTAL</b>	<b>25.02</b>	<b>35.37</b>	<b>13.90</b>	<b>4.50</b>	<b>1.44</b>	<b>0.46</b>	<b>0.33</b>	<b>81.12</b>

## Annex.2

### 1. The volume equations

For all species used ( $\text{height} * 0.45 * (\text{DRC}/2)^2 / 10000 * 3.14159$ )  
and kitir and similar species used ( $.000604 * (\text{crown diameter})^2 * \text{height}$ )

### 2. Volume program

```
SET TALK OFF
USE TREEBUR
STORE 0 TO TLVOL
STORE 0 TO TDVOL
STORE 0 TO TSVOL
STORE 0 TO TCHAR
```



```

STORE 1 TO TPLOT
DO WHILE TPLOT <850
    SUM TOT_LIV_VO TO TLVOL FOR PLOT_NO = TPLOT
    SUM TOT_DEAD TO TDVOL FOR PLOT_NO = TPLOT
    SUM TIMBER TO TSVOL FOR PLOT_NO = TPLOT
    SUM TOT_LIV_VO TO TCHAR FOR USE ='C' .AND. PLOT_NO = TPLOT
    USE SUMALL
    REPLACE LIVE_VOLHA WITH TLVOL*5 FOR PLOT_NO = TPLOT
    REPLACE DEAD_VOLHA WITH TDVOL*5 FOR PLOT_NO = TPLOT
    REPLACE STEM_VOLHA WITH TSVOL*5 FOR PLOT_NO = TPLOT
    REPLACE CHARCOAL WITH TCHAR*5 FOR PLOT_NO =TPLOT
    USE TREEBUR
    TPLOT =TPLOT +1
ENDDO
CLOSE ALL
SET TALK ON

```

### **3. Stems program**

```

SET TALK OFF
USE TREEBUR
STORE 0 TO TDBH
STORE 0 TO TBA
STORE 0 TO TCROWN
STORE 0 TO TSTEM
STORE 0 TO TMSTEM
STORE 0 TO THAS
STORE 1 TO TPLOT
DO WHILE TPLOT <850
    COUNT TO TDBH FOR DBH>0 .AND. PLOT_NO = TPLOT
    SUM BA_DBH TO TBA FOR PLOT_NO = TPLOT
    SUM CROWN_AREA TO TCROWN FOR PLOT_NO = TPLOT
    COUNT TO TMSTEM FOR DBH >9.9 .AND. PLOT_NO = TPLOT
    COUNT TO TSTEM FOR PLOT_NO = TPLOT

```

```
COUNT TO THAS FOR SPEC_CODE ='HAS'.AND. PLOT_NO = TPLOT
USE SUMBUR
  REPLACE DBH_STEMS WITH TDBH*5 FOR PLOT_NO = TPLOT
  REPLACE BASAL_AREA WITH TBA*5 FOR PLOT_NO = TPLOT
  REPLACE CROWN_PERC WITH TCROWN/20 FOR PLOT_NO = TPLOT
  REPLACE STEMS_HA WITH TSTEM*5 FOR PLOT_NO = TPLOT
  REPLACE MERC_STEMS WITH TMSTEM*5 FOR PLOT_NO = TPLOT
USE TREEBUR
  TPLOT =TPLOT +1
ENDDO
CLOSE ALL
SET TALK ON
```